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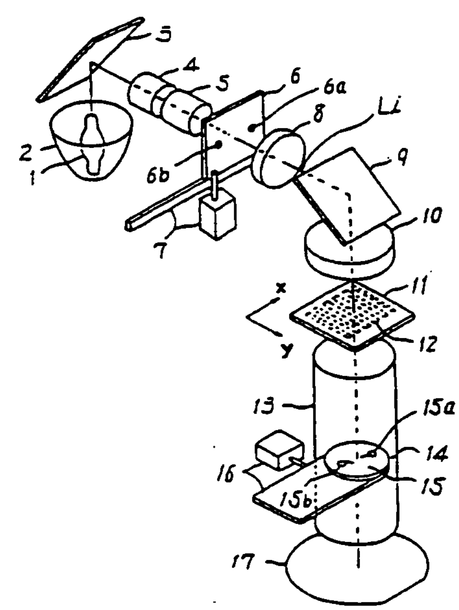

(57) Abstract

A method and a device for transferring minute patterns (12) on the mask (11) to the substratum (17) by means of illuminating optical system (1-10) projecting beams of illuminating light onto the mask (11) and a projection aligner having a projection optical system (13) for projecting images of minute patterns (12) on the substratum (17). Beams of said illuminating light are thrown, as at least a pair of luminous fluxes slantwise facing the mask (11), through a pair of light transmitting windows (6a, 6b) of a spatial filter (6) onto the minute patterns (12), and, as a result, one of diffracted beams of th light of ± first orders caused by minute patterns (12) of the illuminated mask (11) and diffracted beams of zero order pass portions, equidistantly spaced apart from the optical axis of the projection optical system, of or near the Fourier transform surface (14) in the projection optical system (13) for minute patterns (12) on the mask (11) so that projected images may be formed to be sharp in contrast and high in resoluti n on the substratum (17) at a large focal depth.

(57) 要約

マスク(11)に照明光を照射する照明光学系(1-10)と、この照明されたマスクの微細パターン(12)の像を基板(17)上に投影するための投影光学系(13)とを有する投影露光装置によってマスク(11)の微細パターン(12)を基板(17)上に転写する方法と装置。前記照明光は空間フィルタ(6) の透光窓(6a,6b) の対を介してマスク(11)に対して傾いて向いあう少なくとも一対の光束として微細パターン(12)に照射され、それによって照明されたマスク(11)の微細パターン(12)から生じる±1次回折光のいずれか一方と0次回折光とがマスク(11)の微細パターン(12)に対する投影光学系(13)中のフーリエ変換面(14)またはその近傍において投影光学系の光軸から互いに等距離だけ離れて通過し、基板(17)上に明暗コントラストの強い高解像度の投影像を深い焦点深度で形成する。（図1）

明　細　書

露光方法および装置

[技術分野]

本発明は露光方法および装置に関し、更に詳しくは規則的な微細パターンをもつ半導体メモリ素子や液晶素子等のためのリソグラフィ工程に用いられる投影露光方法および装置に関するものである。

[背景技術]

半導体メモリや液晶素子の製造には、一般的に、フォトリソグラフィ手法によってマスクパターンを基板上に転写する方法が採用される。この場合、紫外線等の露光のための照明光は、感光レジスト層が表面に形成された基板上に、マスクパターンを形成したマスクを介して照射され、それにより基板上にはマスクパターンが写真的に転写される。

半導体メモリ素子や液晶素子等の微細なマスクパターンの一般的なものは、縦または横に等間隔で配列された規則的な格子パターンと見なすことができる。言い換えれば、この種のマスクパターンにおいて最も密集したパターン領域には、基板上に形成可能な最小の線幅を実現するところの等間隔の透明ラインと不透明ラインとをX方向および／またはY方向に交互に配列した格子パターンが形成され、一方、その他の領域では比較的ゆるい微細度のパターンが形成される。またいずれにせよ斜めのパターンは例外的である。

更に、一般的な感光レジスト材料は非線形の感光特性を有し、あるレベル以上の受光量を与えると急速に化学変化が進むが、それ以下の受光量では、ほとんど化学変化が進行しない。従って、基板上におけるマスクパターン投影像については、明部と暗部の光量差が充分に確保されていさえすれば、明部と暗部の境界のコントラストは多少低くても、マスクパターンどおりの所要のレジスト像を得ることができるという背景がある。

近年、半導体メモリや液晶素子のパターン構成の微細化に伴って、マスクパタ

ーンを基板上に縮小投影して転写するステッパー等の投影露光装置が多用されてきており、露光用の照明光としても、より短い波長を有すると共に波長分布幅の狭い特殊な紫外線が使用されるようになった。ここで、波長分布幅を狭くする理由は、露光装置の投影光学系の色収差による投影像の像質の劣化を除くためであり、より短い波長を選択する理由は、投影像のコントラストを向上させるためである。しかし、この照明光の短波長化も、要求されるマスクパターンの一層の微細化、例えばサブミクロンオーダの線幅の投影露光に対しては、適当な光源が無いことや、レンズ材料やレジスト材料の制約等から限界を迎えているのが現状である。

このような微細化されたマスクパターンにおいては、パターンの解像線幅の要求値が照明光の波長に接近するため、照明光がマスクパターンを透過する時に発生する回折光の影響が無視できず、基板上のマスクパターン投影像における十分な明暗コントラストの確保が困難となり、特にパターンのラインエッジの明暗コントラストが著しく低下する。

すなわち、マスクに対して上方から入射する照明光によりマスクパターン上の各点において発生される0次、±1次、および±2次以上の各回折光は、投影光学系を経て、これらの各点と共役な基板上のそれぞれの点に再集合して結像するが、より微細なマスクパターンに対して±1次および±2次以上の回折光は0次回折光よりも回折角度がさらに大きくなるため、基板上へより浅い角度で入射するようになり、その結果、投影像の焦点深度が著しく低下して、レジスト層の厚みの一部にしか充分な露光エネルギーを供給できなくなるという問題を発生させた。

このような焦点深度の低下に対する一つの対策として、日本特許出願公開No. 2-50417（1990.2.20公開）には、照明光学系と投影光学系に光軸と同心の絞りを設けて照明光のマスクに対する入射角度を制約するとともに、マスクパターンに応じて該絞りの開口径を調整して、試料基板上の投影像の明暗コントラストを維持しつつ焦点深度を確保することが示されている。しかし、この公知の方式においても、ほぼ垂直に基板表面に達する0次回折光に対して、±1次以上の回折光

はその回折角度が依然として大きいため殆どの部分が投影レンズの視野からはみ出してしまい、結果的に基板上にはほぼ0次光成分のみからなるコントラストの悪いマスクパターン投影像しか得られなかった。

またこの場合、±1次回折光の一部は投影レンズの視野内に納まって基板に達する可能性があるが、この一部の±1次回折光は、0次回折光が基板にほぼ垂直に入射するのに対して、それよりも浅い角度で基板に入射するため、やはり十分な焦点深度が確保できないことが指摘された。

一方、ティー・イー・ジュウエル等（T.E.Jewell et al）に付与されたアメリカ合衆国特許第 4,947,413号には、オフアクシスの照明光源を用い、投影光学系内のフーリエ変換面内で空間フィルタ処理を利用してマスクパターンからの0次回折光と＋または－1次回折光の一方のみとを干渉可能にすることにより、基板上に高いコントラストのパターン投影像を高解像度で形成する投影リソグラフィ方式が開示されている。しかしながらこの方式では、照明光源をマスクに対して斜めに向けたオフアクシス配置としなければならず、また0次回折光と＋または－1次回折光の一方のみとを干渉させるだけであるので0次回折光と1次回折光との光量差のアンバランスによってそれらの干渉で得られるパターン像のエッジの明暗コントラストは未だ不充分であった。

［発明の開示］

本発明の目的は、位相シフト手段をもたない通常のマスクにおける微細なマスクパターンから基板上で十分な明暗コントラストの投影像を深い焦点深度で得ることのできる投影露光方法および装置を提供することであり、より具体的な目的は、上述のように照明光が狭い波長分布を持つことと、マスクパターンが実質的に回折格子とみなせることと、レジスト材料が受光量に対して非線形の感光特性を有すること等を積極的に利用して、照明光の波長を同じとした場合に、より一層微細なマスクパターンのレジスト像を形成できるようにすることである。

本発明の基本理念に従えば、少なくとも部分的に微細パターンが形成されたマスクを照明光によって照明するための照明光学系と、この照明された前記微細パ

ターンの像を基板上に投影するための投影光学系とを有する露光装置を使用して前記マスクの微細パターンが基板上に転写され、その際に、前記照明光は少なくとも２個所から前記マスクに特定の入射角で斜めに向いあうように入射され、この斜めの照明光によって前記微細パターンから生じる±１次回折光のいずれか一方と０次回折光とが、前記マスクの微細パターンに対する前記投影光学系中のフーリエ変換面またはその近傍において前記投影光学系の光軸から互いにほぼ等距離だけ離れた光路を通過し、主に前記±１次回折光のいずれか一方と０次回折光とによって前記基板上に前記微細パターンの投影像が形成される。この場合、前記±１次回折光のいずれか一方と０次回折光とを除く他の不要な光は実質的に基板面へ到達しない。この目的のための光学的手段として、主に空間フィルタ手段が前記照明光学系および／または前記投影光学系に配置される。また照明光学系は光軸に沿って照明光を導く構成をとることができ、照明光を前記マスクに特定の入射角で入射するため、前記照明光学系には、前記マスクの手前に光学要素、例えばコンデンサレンズ手段が配置される。

本発明の好ましい態様に係る露光装置は、マスクに照明光を照射する照明光学系と、この照明されたマスクの微細パターンの像を基板上に投影するための投影光学系と、前記マスクの微細パターンに対する前記照明光学系および／または前記投影光学系中のフーリエ変換面もしくはその近傍に配置された空間フィルタ手段とを備えており、前記空間フィルタ手段は、それが配置された前記照明光学系および／または前記投影光学系の光軸から離れた位置に周囲よりも比較的高い光透過率をもつようにそれぞれ独立した限定領域によって画定された少なくとも２つの窓手段を有している。この空間フィルタ手段が配置される前記フーリエ変換面は、例えば前記照明光学系のほぼ瞳面上の位置、または該瞳面のほぼ共役面上の位置、または前記投影光学系のほぼ瞳面上の位置にあり、前記空間フィルタ手段はこれら位置のうちの少なくとも１個所に配置される得る。

本発明の一つの好ましい態様において、前記空間フィルタ手段は、それが配置された前記照明光学系および／または前記投影光学系の光軸に対してほぼ対称な対をなす位置に前記２つの窓手段を有している。

本発明別の好ましい態様において、空間フィルタ手段における窓手段の数は2n個（nは自然数）である。また前記窓手段は、好ましくは前記微細パターンのフーリエ変換パターンに基づいて定められた複数の位置に設けられる。

本発明の別の好ましい態様においては、前記照明光学系はフライアイレンズ等のオプチカルインテグレータを備えており、この場合、前記空間フィルタ手段はオプチカルインテグレータの射出端の近傍位置に配置されている。

本発明において、空間フィルタ手段の前記窓手段を除く部分は一般に暗部、すなわち光透過率が実質的に０％もしくはそれに近い遮光部、または窓手段の光透過率よりは少ない予め定められた光透過率をもつ減光部として形成されている。

本発明の更に別の好ましい態様においては、前記空間フィルタ手段は前記照明中に配置され、その各窓手段の位置は、前記微細パターンから発生する±１次回折光のいずれか一方と０次回折光とが前記マスクの微細パターンに対する前記投影光学系中のフーリエ変換面またはその近傍位置において前記投影光学系の光軸からほぼ等距離だけ離れて別々に通過するように定められている。

本発明の更に別の好ましい態様においては、前記空間フィルタ手段が前記照明光学系中に配置され、前記空間フィルタ手段が前記照明光学系の光軸に関してほぼ対称な対をなす第１の窓手段と第２の窓手段とを有し、この第１の窓手段と第２の窓手段の各位置は、第１の窓手段を通過して前記マスクへ至る照明光束の照射によって前記微細パターンから発生する±１次回折光のいずれか一方と０次回折光との二つの回折光束と、第２の窓手段を通過して前記マスクへ至る照明光束の照射によって前記微細パターンから発生する±１次回折光のいずれか一方と０次回折光との二つの回折光束とが、前記投影光学系中の前記フーリエ変換面またはその近傍位置において投影光学系の光軸からほぼ等距離で離れた別々の第１と第２の光路を交互(alternatively) に、即ち第１の窓手段からの照明光による±１次回折光のいずれか一方と第２の窓手段からの照明光による０次回折光との二つの回折光束が例えば第１の光路を通過し、第２の窓手段からの照明光による±１次回折光のいずれか一方と第１の窓手段からの照明光による０次回折光との二つの回折光束が例えば第２の光路を通過するように定められている。

本発明の別の好ましい態様によれば、前記露光装置は、前記窓手段の前記光軸回りの角度位置および前記光軸からの間隔距離の少なくとも一方をマスクの微細パターンに対応して調整または切換えのために変える駆動手段を備えている。この駆動手段は、前記空間フィルタ手段として幾つかの窓手段を有する遮光板または減光板を用いるときは、遮光板または透光板を別の位置に窓手段をもつものと交換する機構によって構成され、また前記空間フィルタ手段として任意の位置の限定領域を透明化および不透明化できる電気光学素子、例えば液晶素子やエレクトロクロミック素子を用いるときは、この電気光学素子を前記限定領域の透明化および不透明化のために駆動する電気回路手段によって構成され得る。

従来の投影露光装置では、マスクに対して上方から種々の入射角で入射する照明光が無差別に用いられ、マスクパターンで発生した0次、±1次、および±2次以上の各回折光がほぼ無秩序な向きに向けられ、各回折光が投影光学系を通過して基板上に結像する位置は別々の異なった位置であった。これに対して、本発明の投影露光装置では、マスクパターンに対して光軸に直交する平面内の特定の位置から特定の方向と角度で斜めに入射する照明光が選択的に用いられ、この照明光によってマスクパターンから発生した±1次回折光のいずれか一方と0次回折光とが基板上に主に導かれて、基板上における微細パターンの投影像の形成に主に関与する。すなわち本発明においては、この目的のためにマスクパターンに応じた空間フィルタ手段が利用され、この空間フィルタ手段によって照明光のなかから最適な±1次回折光のいずれか一方と0次回折光だけを主に選択して基板上に導くことにより、微細パターンのエッジの明暗コントラストが従来よりも大きく、そして焦点深度の深いパターン投影像を基板上に得るものである。

ここで、本発明における空間フィルタ手段の適用には以下の二通りのやり方がある。すなわち、その第1はマスクの手前で照明光束をそのビーム断面の一部で遮光または減光し、主要な照明光として、光軸に直交する平面内の特定の位置から特定の方向と角度で斜めに入射する照明光を選択するやり方であり、このためには前記空間フィルタ手段は前記照明光学系中の前記フーリエ変換面またはその近傍位置に配置される。第2は、種々の入射角をもつ照明光によって照明された

マスクパターンから発生する種々の回折光成分のうちの、光軸に直交する平面内の特定の位置から特定の方向と角度で斜めに入射する照明光によってマスクパターンから発生した±1次回折光のいずれか一方と0次回折光との両成分光を投影光学系内で選択するやり方であり、このためには前記空間フィルタ手段は投影光学系中の前記フーリエ変換面またはその近傍位置に配置される。これら第1と第2のやり方を併用してもよく、いずれにせよ前記空間フィルタ手段は、基板上におけるパターン投影像の形成に関与する光を、特定の傾斜角で入射する斜めの照明光によりマスクパターンから発生する±1次回折光のいずれか一方と0次回折光とに制限し、他の不要な光が基板面に到達するのを制限する役目を果たす。

照明光学系中の前記フーリエ変換面またはその近傍位置に空間フィルタ手段を配置した場合、所定の波長を有する照明光が、光軸回りの特定の角度方向にある所定の離心位置から特定の入射角で回折格子状のマスクパターンに入射し、その結果として、理論的には投影光学系のフーリエ変換面またはその近傍位置に、フーリエ展開された0次、1次、および2次以上の各回折光によるスポット列が形成される。ただし、通常の投影露光装置では2次以上の高次回折光は投影光学系のレンズ鏡筒によってケラレ(eclipsed)てしまう。

照明光学系中の前記フーリエ変換面またはその近傍位置に配置した空間フィルタ手段はまた、マスクに対してほぼ垂直に入射する照明光を遮光または減光し、光軸回りの特定の角度方向にある所定の離心位置から特定の入射角でマスクへ入射すべき照明光を選択的に高い光透過率で通過させる。ここで、2次以上の高次回折光が邪魔な場合には、さらに投影光学系中の前記フーリエ変換面またはその近傍に別の空間フィルタ手段を設けてこれを遮光ないし減光する。これにより、基板上には、好ましい入射角の照明光によってマスクパターンから発生した0次回折光と1次回折光とによるハイコントラストの投影パターン像が形成される。

ここで、半導体メモリ素子や液晶素子のためのマスクパターンにおいては、多くの場合、マスクパターン中で高解像度の転写が必要とされる部分のパターンは基本的に等間隔の透明・不透明ラインを規則的に交互に配列した格子状パターンによって構成されており、これは一般的にはデューティ比0.5 の矩形波状の繰り

返しパターンとみなすことができる。照明光学系中のフーリエ変換面またはその近傍位置に空間フィルタ手段を設けた場合、この格子状パターンから発生する回折光によって、投影光学系のフーリエ変換面には格子のラインを横断する方向（ラインの配列方向）に分布する０次、±１次、および±２次以上の各次数回折光のスポットが形成される。このとき、一般的な矩形波のフーリエ展開として知られているのと同じように、０次回折光は基板上の投影像における光量の基準レベルを与え、±１次回折光は格子と同周期の正弦波の光量変化成分であり、これらの回折光成分が基板上に集光されると、互いの干渉によって基板上にはレジスト層の感光に必要十分な光量で高い明暗コントラストを持った結像パターンが得られる。

またこの場合、一般的な半導体メモリ素子や液晶素子のためのマスクパターンは、マスク上に配列された縦方向と横方向の各格子を複数個組合せたものとみなせるから、各格子に対して光軸回りの最適な角度方向の離心位置と入射角をもつ照明光束がそれぞれ確保されるように空間フィルタ手段を準備すれば、投影光学系のフーリエ変換面に形成されるフーリエパターンは、各格子のライン配列方向に応じた角度方向に並んだ、照明光の波長と格子のラインピッチとに応じた相互間隔のスポット群を形成する。この各スポットの光の強度は、格子のピッチ数と回折光の次数とに依存している。

このことから解るように、必要なスポット位置に対応した位置にのみ窓手段を設けた空間フィルタ手段を投影光学系内に配置することによって基板へ至る回折光の選択を行っても、同様の効果を得ることができる。この場合、投影光学系中のフーリエ変換面またはその近傍位置に配置される空間フィルタ手段は、該フーリエ変換面における有用な回折光のスポット位置に窓手段を有し、それにより有用な回折光を選択的に通過させ、一方、基板面でのコントラスト低下の原因になる不要な回折光を遮断する。

このように、空間フィルタ手段の窓の個数と位置はマスクパターンに応じたそれぞれ異なる固有なものであるから、空間フィルタ手段は、当然のことながらマスクが交換されれば一緒に交換され、かつマスクに対して厳密に位置調整される

べきものである。

次に、マスクパターンに対して光軸回りの特定の角度方向にある所定の離心位置から特定の入射角の照明光を入射し、該照明光によってマスクパターンから発生される±1次回折光のいずれか一方と0次回折光とを用いて基板上に結像パターンを形成することにより、焦点深度が深くなる理由を説明する。

一般に、基板が投影光学系の焦点位置に一致している場合には、マスク上の1点から出て基板上の1点に達する各次数の回折光は、投影光学系のどの部分を通るものであってもすべて等しい光路長を有するから、従来のように0次回折光が投影光学系の瞳面のほぼ中心を貫通する場合でも、0次回折光とその他の次数の回折光とで光路長は相等しく、フーリエ変換面のほぼ中心を貫通する光束の光路長を基準としてフーリエ変換面の任意の位置を通過する光束の光路長と前記基準光路長との差、即ち波面収差は0である。しかし、基板が投影光学系の焦点位置に一致していないデフォーカス位置にある場合、投影光学系中のフーリエ変換面の外周寄り部分を通過して基板に斜めに入射する1次以上の次数の回折光の光路長は、前記フーリエ変換面の中心付近を通過する0次回折光に対して、基板が焦点前方に位置してデフォーカス量が負の場合には短くなり、また基板が焦点後方に位置してデフォーカス量が正の場合には長くなり、これらの光路長の差は、各次数の回折光の基板への入射角の差に応じた量をもち、これはデフォーカスによる波面収差と呼ばれている。即ち、このようなデフォーカスの存在によって、1次以上の次数の各回折光は0次回折光に対して相互に波面収差を形成し、焦点位置の前後における結像パターンのぼけを発生する。この波面収差ΔWは、次式

$$\Delta W = 1/2 \times (NA)^2 \cdot \Delta f$$

ただし、Δf：デフォーカス量

NA：フーリエ変換面上の中心からの距離を開口数で表わした値

で表わされる。従って、フーリエ変換面のほぼ中心を貫通する0次回折光（ΔW＝0）に対して、フーリエ変換面の外周寄りの半径r_1の位置を通過する1次回折光では、

$$\Delta W = 1/2 \times r_1^2 \times \Delta f$$

の波面収差を持つこととなり、この波面収差の存在が従来技術における焦点位置の前後での解像度を劣化させ、焦点深度を浅くしていることの原因である。

これに対して、本発明の露光装置では、前記空間フィルタ手段を配置することによって、特定の入射角をもつ照明光束によってマスクパターンから生じる±次回折光のいずれか一方と0次回折光とが、投影光学系中のフーリエ変換面上のほぼ中心対称な離心位置（共に離心半径r_2とする）を通るようにしている。従って本発明の露光装置の場合、投影光学系の焦点の前後における前記0次回折光と1次回折光の波面収差は、いずれも

$$\Delta W = 1/2 \times r_2{}^2 \Delta f$$

となり、互いに等しくなる。従ってデフォーカスに伴う波面収差による像質の劣化（ぼけ）が無く、すなわち、この分だけ深い焦点深度が得られるのである。

また、照明光学系中に空間フィルタ手段を配置した場合、その光軸対称の一対をなす各窓手段を通った一対の照明光は、マスク面に対して斜めに且つ法線の両側で対称的に入射する光束となるが、これら光束によってマスクの格子状パターンから生じる±1次回折光のどちらか一方は、投影光学系の光軸についてその0次回折光と光軸に関して対称な位置を通り、基板に0次光と同程度の深い入射角で入射する。これにより、結像に関与する投影光学系の実質的な開口数が小さくなり、より深い焦点深度が得られる。

このように、本発明のにおいては、光軸を挟む対構成の窓を有する空間フィルタ手段により、好ましい入射角の照明光束によってマスクの微細パターンから発生される回折光のうちの好ましい次数、即ち0次回折光と1次回折光とを選択的に基板上の同一位置に集光させてパターン像を結像させるから、従来では解像不能とされた微細なパターンでも、照明光や投影光学系の変更なしに、基板上の結像パターンにおけるレジスト層の感光に十分な明暗コントラストと十分に深い焦点深度とを確保できるものである。

照明光学系中に空間フィルタ手段を配置する場合、空間フィルタ手段の一対の窓は、一方の窓を通過した照明光によってマスクの微細な格子状パタンーンから生じる±一次回折光のいずれか一方と、他方の窓を通過した照明光によって生じ

る０次回折光とが、投影光学系のフーリエ変換面上のほぼ同一の離心位置を通過するように、それらの相互間隔が定められている。

投影光学系中に空間フィルタ手段を配置する場合、空間フィルタ手段の一対の窓は、前記好ましい入射角を有する照明光によってマスクの微細な格子状パターンから発生される±１次回折光のいずれか一方と０次回折光とが、夫々別々の離心位置を通過するように、それらの相互間隔が定められている。

本発明の露光装置においては、適当な調整機構を用いて、空間フィルタを光軸回りに或る角度だけ回転させ、または配置面内で平行移動させることにより、マスクパターンに対する空間フィルタの窓の位置ずれを補正できる。また、対をなす窓の相互間隔を調整可能に構成して、マスクパターンのフーリエパターンにより良く適合させることもできる。この場合、調整機構により、空間フィルタの窓の位置または窓間の間隔を変化できるように構成すれば、マスクと空間フィルタの窓との最適な位置関係を得ることが可能であり、また、別のパターンを有するマスクに対しても同一の空間フィルタを併用できるようになる。

本発明の別の態様では、液晶素子やエレクトロクロミック素子等の電気光学素子を組込んだ空間フィルタが採用され、電気信号により窓の位置および寸法の調整を行うことができるようになっている。この場合、電気信号によって、電気光学素子で構成された空間フィルタの任意の位置の限定された領域を透明・不透明に自由に調整できるから、マスクパターンと空間フィルタの窓との最適な位置関係を得ることが可能であり、勿論、この場合も別のパターンを有するマスクに対して空間フィルタを共用することが可能である。

本発明の上述およびそれ以外の特徴と利点を一層理解し易くするため、本発明の好適な幾つかの実施例を添付図面と共に以下に説明する。

［図面の簡単な説明］

図１は、本発明の一実施例に係る露光装置の構成を示す斜視図、

図２は、前記実施例の原理的な光路構成を示す模式図、

図３は、前記実施例に係る露光装置の照明光学系中に配置される空間フィルタ

の一例を示す平面図、

図４は、マスクパターンの一例を示す模式平面図、

図５ａおよび５ｂは、空間フィルタの別々の例を示す模式平面図、

図６ａおよび６ｂは、図５ａと５ｂに各々対応して、投影光学系のフーリエ変換面における回折光の強度分布を模式的に示す図、

図７は、参考例に係る投影露光装置の光路構成を示す模式図、

図８は、前図の投影光学系のフーリエ変換面における回折光の強度分布を模式的に示す図

図９は、別の参考例に係る投影露光装置の光路構成を示す模式図、

図１０は、前図の参考例の投影光学系のフーリエ変換面における回折光の強度分布を模式多岐に示す図、

図１１は、本発明の実施例における投影像の光量分布を示す線図、

図１２は、図７の参考例（σ＝０．５とした場合）における投影像の光量分布を示す線図、

図１３は、図７の参考例（σ＝０．９とした場合）における投影像の光量分布を示す線図、

図１４は、図９の別の参考例における投影像の光量分布を示す線図である。

［発明を実施するための最良の形態］

図１に示す実施例において、マスク１１には、代表的な微細パターンの一例として、デューティ比０．５の１次元の格子状パターン１２が形成されている。マスク１１を照明する照明光学系は、水銀ランプ１、楕円面鏡２、コールドミラー３、集光光学素子４、光学的インテグレータ素子５、リレーレンズ８（瞳リレー系）、ミラー９、コンデンサーレンズ１０からなり、照明光学系のフーリエ変換面、即ち、ここでは水銀ランプ１の２次光源像が形成されるインテグレータ素子５の射出端面の近傍（換言すれば、照明光学系の瞳面またはその共役面、およびそれらの近傍の位置）には空間フィルタ６が配置されている。この空間フィルタ６には、マスクパターン１２の２次元フーリエ変換に基づいて位置と大きさが定

められる一対の透光窓６ａ、６ｂが設けられている。

またパターン１２の像をウェハ１７上に投影する投影光学系１３のフーリエ変換面１４にも、同様に透光窓１５ａ、１５ｂを備えた空間フィルタ１５が配置されている。ここで、本実施例では、マスクパターン１２として１次元の回折格子パターンを用いているので、空間フィルタ６および１５には、共に一対の透光窓６ａ，６ｂまたは１５ａ，１５ｂが形成されており、それぞれの配置面内で一対の透光窓が光学系の光軸を挟んでほぼ対称位置に、且つその配列方向が格子パターン１２のラインピッチ方向と光学的に揃うように配置されている。また空間フィルタ６と１５には、それぞれモータやカム等で構成される駆動機構７または１６が設けられており、マスクパターンに応じて空間フィルタ６，１５が別のものと交換可能で、かつ配置面内での透光窓６ａ，６ｂまたは１５ａ，１５ｂの位置の微調整が可能となっている。尚、空間フィルタ６，１５の透光窓６ａ，６ｂおよび１５ａ，１５ｂの開口形状は任意でよく、図１では限定を意図しない例として、ともに円形開口の場合が示されている。また、この空間フィルタ６，１５は遮光板に透光窓としての一対の開口を形成したものであるが、空間フィルタ６，１５は液晶素子やエレクトロクロミック素子等の電気光学的素子によって構成することもあり、その場合は図示した駆動機構７や１６は電気光学的素子の限定された任意の領域に適宜の大きさ・形状の透光部を出現させるための電気回路装置によって構成される。

このように構成された露光装置において、楕円面鏡２の第１焦点に配置された水銀ランプ１から発生された照明光は、楕円面鏡２とコールドミラー３で反射されて、楕円面鏡２の第２焦点に集光された後に、コリメータレンズや光束分布補正用のコーン状プリズム等からなる集光光学素子４を通過して、フライアイレンズ群からなるインテグレータ素子５により、空間フィルタ６の配置面上に実質的な面光源を形成する。尚、本実施例ではインテグレータ素子５の２次光源像が投影光学系１３のフーリエ変換面１４に形成される、いわゆるケラー照明となっている。この面光源自体は、従来同様に、マスクに上方から種々の入射角で入射する照明光を与えるはずものであるが、ここではコンデンサーレンズ１０の手前に

空間フィルタ６が配置されているため、空間フィルタ６の２つの透光窓６ａ，６ｂを通過する平行光束だけがリレーレンズ８、ミラー９、コンデンサーレンズ１０を介して、格子パターン１２のラインを横切る面内で光軸対称に斜めの所定入射角でマスク１１へ入射する。

前記平行光束がマスク１１のパターン１２に入射すると、パターン１２からは０次、±１次、および±２次以上の各回折光が生じる。ここで、前記平行光束は照明光学系のフーリエ変換面１４に配置された空間フィルタ６の透光窓６ａ，６ｂにより光軸からの距離と光軸回りの位置とが定められ、またコンデンサレンズ１０によりマスク１１のパターン１２への入射角が定められているので、投影光学系１３に入射するのは前記各次数の回折光のうちの±１次回折光のいずれか一方と０次回折光とがその殆どとなり、その他の回折光は極く僅かとなる。その結果、投影光学系１３のフーリエ変換面には±１次回折光のいずれか一方と０次回折光との主要な回折光スポットと、その他の不要な次数の回折光スポットとがフーリエ展開パターンに従って形成される。投影光学系１３のフーリエ変換面に配置された別の空間フィルタ１４は、前記主要な回折光だけを選択的にウェハ１７側に通過させ、その他の次数の不要な回折光を遮断する。この場合、前記±１次回折光のいずれか一方と０次回折光との主要な回折光が最大強度で通過できるように、また前記不要な回折光が完全に遮断されるように、駆動機構７、１６を用いて、マスク１１のパターン１２に対する空間フィルタ６、１５の位置調整が行われる。

図２は、本実施例の露光装置における照明光の基本的な光路構成を模式的に示している。ここでは、図示の都合上、空間フィルタ６がコンデンサレンズ１０の直上に配置されているが、この位置はリレーレンズ８に対して図１の空間フィルタ６と共役な面であり、機能と効果に関して図１の場合と実質的に同じである。

図２において、投影光学系１３の開口数をNA、照明光の波長をλとすると、パターン１２のピッチはλ／NAの0.75倍、パターン１２のライン・アンド・スペースの比は１：１（格子のデューティ比を0.5)としてある。この場合、パターン１２の波長λを考慮したフーリエ変換ｑ(u,v) は、パターン１２をｐ(x,y) とする

と、

$$q(u,v) = \iint p(x,y) \cdot \exp\{-2\pi i(ux+vy)/\lambda\}\,dxdy$$

で与えられる。更に、パターン１２が、第４図に示されるように、上下すなわちｙ方向には一様で、ｘ方向に規則的な変化をもつ場合は、ｘ方向のライン・アンド・スペースの比が１：１、ラインピッチが0.75λ／NAであるとすると、

$$q(u,v) = q_1(u) \times q_2(v)$$

と表わすことができ、従って

$q_1(u) = 1,$	$u = 0$
$q_1(u) = 0.637,$	$u = \pm NA/0.75$
$q_1(u) = -0.212,$	$u = \pm 3NA/0.75$
:	:
$q_1(u) = 0.637/(2n-1)(-1)^{(n+1)},$	$u = \pm(2n-1) \cdot NA/0.75$
$q_1(u) = 0,$	uは上記以外

および、

$q_2(v) = 1,$	$v = 0$
$q_2(v) = 0,$	$v \neq 0$

と表わすことができる。

図３と図５ａは、それぞれ本実施例に供される照明光学系用の空間フィルタ６と投影光学系用の空間フィルタ１５の平面図である。

空間フィルタ６と１５は、上記フーリエ変換のエネルギー分布$|q(u,v)|^2$のピーク位置

$$(u,v) = (0,\ 0),\ (\pm NA/0.75,\ 0),\ (\pm 3NA/0.75,\ 0) \cdots$$

の1/2であるところの

$$(u,v) = (0,\ 0),\ (\pm NA/1.5,\ 0),\ (\pm 2NA,\ 0) \cdots$$

のうち、投影光学系１３の開口数以内に入る位置、

$$(u,v) = (\pm NA/1.5,\ 0)$$

およびその近傍位置を透光窓６ａ，６ｂと１５ａ，１５ｂとし、

$$(u,v) = (0,\ 0)$$

の位置を遮光部としたものである。

尚、空間フィルタ６、１５は、その位置

(u, v) ＝(0, 0)

がそれぞれ照明光学系（１～１０）および投影光学系１３の光軸と一致するように、図１の駆動機構７または１６により位置調整される。空間フィルタ６と１５は、不透明な金属板の一部を取り去って透光窓を形成したものでも、またガラス等の透明保持板上に不透明な金属薄膜等をパターンニングして透光窓を形成したものでもよい。また図１に示した例においては、照明光源として水銀ランプ１を例示したが、これはレーザ光源等の別の光源であってもよい。更にこの実施例ではマスク１１のパターン１２としてｘ方向のみにデューティ１：１で変化するライン・アンド・スペース・パターンを示したが、この他の任意の複数方向に規則的に変化するパターンについても本発明は適用可能である。

図２において、ラインピッチが0.75λ／NAであるパターン１２に対して、照明光学系中のパターン１２のフーリエ変換面に図示のような空間フィルタ６を設けることにより、パターン１２を照明する照明光Ｌｉは平行光束Ｌｉℓ、Ｌｉｒのごとく制限される。この照明光Ｌｉℓ、Ｌｉｒがパターン１２に照射されるとパターン１２からその回折光が発生する。

照明光Ｌｉℓの０次回折光をＬ１０、＋１次回折光をＬℓ１とし、照明光Ｌｉｒの０次回折光をＬｒ０、－１次回折光をＬｒ１とすると、回折光Ｌℓ０と回折光Ｌℓ１、回折光Ｌｒ０と回折光Ｌｒ１の離角はともに、

sinθ＝λ／（パターン１２のラインピッチ）

＝λ／（0.75λ／NA）

＝NA／0.75

となるが、もともと、入射光Ｌｉℓと入射光Ｌｉｒは２NA／1.5 だけ離れているので、投影光学系１３のフーリエ変換面では、回折光Ｌℓ０と回折光Ｌｒ１が共に同じ第１の光路を通り、また回折光Ｌｒ０と回折光Ｌℓ１が共に同じ第２の光路を通ることになる。ここで第１の光路と第２の光路とは投影光学系１３の光軸から対称的に等距離だけ離れている。

図６ａに投影光学系１３のフーリエ変換面１４での回折光の強度分布を模式的に示す。図６において、フーリエ変換面１４に形成されたスポット２２ℓは回折光Ｌｒ０とＬℓ１が、またスポット２２ｒは回折光Ｌℓ０とＬｒ１がそれぞれ集束したスポットである。

図６ａより明らかなように、本実施例においては、ラインピッチがλ／NAより微細な0.75λ／NAのパターン１２からの０次回折光と＋１次又は－１次回折光を投影光学系１３を介してほぼ１００％ウェハー１７上へ集光させることができ、従って、従来の露光装置における解像度の限界であったピッチ（λ／NA）よりもさらに細いパターンの場合も、マスクパターンのラインピッチに応じた諸元の透光窓をもつ空間フィルタを用いることにより、充分な解像度での露光転写が可能である。

尚、図５ｂはマスクパターンがｘおよびｙ方向に交差するライン・アンド・スペース・パターンの場合に用いられる空間フィルタを示している。また図６ｂはその場合に投影光学系のフーリエ変換面に形成される回折光の対応するスポットの様子を示している。

次に、本実施例の露光装置における基板１７上のパターン解像度を、種々の参考例に係る露光装置におけるそれとの比較において以下に説明する。

＝参考例の場合＝

図７と図８は、参考例として掲げる前述の日本公開特許No.2-50417に示された投影露光装置における照明光の光路構成（図７）と、投影光学系のフーリエ変換面における光量分布（図８）とを夫々模式的に示している。尚、これらの図においては、本発明の前記実施例に係る装置と同じ作用・機能の部材に図２中の符号と同じ符号を付してある。

図７において、照明光学系のフーリエ変換面には開口絞り（円形の透光窓を光軸と同心に備えた空間フィルタ）６Ａが設けられ、マスク１１に対する照明光の入射角を制限している。マスク１１のパターン１２から発生した０次回折光（実線）と±１次回折光（破線）とは、共に投影光学系１３に入射して別々の光路を進み、ここでは図８に示すごとくフーリエ変換面１４において＋１次回折光のス

ポット２０ℓと、０次回折光のスポット２０ｃと、－１次回折光のスポット２０ｒとが別々の位置に離れて形成される。

また図９と図１０は、別の参考例としての投影型露光装置における照明光の光路構成（図９）と、投影光学系のフーリエ変換面における光量分布（図１０）とを夫々模式的に示している。この別の参考例では、図７の開口絞り６Ａの代りに光軸と同心の円環状の透光窓を設けた空間フィルタ６Ｂが採用されている。

図９において、照明光学系のフーリエ変換面には円環状の透光窓を光軸と同心に形成した空間フィルタ６Ｂが設けられ、マスク１１に対して照明光が斜めに、すなわち逆円錐状に入射されている。これにより、少なくともパターン１２のラインピッチ方向に光軸を横切る面内では、図２に示した本願発明の実施例の場合と同様に、０次回折光（実線）が１次回折光（破線）並みに斜めに投影光学系に入射され、反対側から来た別の１次回折光と一部重なって投影光学系を通過し、ウエハ１７にまで達して投影像を形成する。このとき、投影光学系１３のフーリエ変換面１４には図１０に示すように光軸と同心のドーナッツ状の０次回折光のスポット２１ｃと、それに隣接して一部重なる＋１次回折光のスポット２１ℓおよび－１次回折光のスポット２１ｒとが形成される。ここで、スポット２１ℓと２１ｒとの大部分は投影光学系１３の外側にはみ出し、これらはみ出した部分の光は投影光学系の鏡筒によってケラレてしまう。

＝本発明の実施例の場合＝

図１１～図１４は、図２に示した本発明の実施例におけるウェハ１７上の投影像の光強度Ｉの分布を図７と図９の場合と比較した線図である。この光強度分布は、投影光学系のNAを0.5、照明光の波長λを 0.365μｍ、マスクパターン１２のパターンラインピッチを投影光学系１３の倍率から求めたウェハ１７上での換算で0.5 μｍ（ほぼ０．６８５×λ／NA）として、基板上でパターン１２のラインピッチ方向に光軸を横切る面内について計算により求めた結果に従っている。

図１１は、本発明の前述の実施例（図２）に従った露光装置によって基板上に形成された投影像の光強度分布を示し、これは、パターンのエッジの明暗コントラストを十分にもっていることが判る。

図１２は、図７の参考例において開口絞り６Ａの径を比較的小さく、照明光学系の開口数と投影光学系の開口数との比、いわゆるσ値を０．５とした場合の基板上の投影像の光強度分布を示している。ここでは、照明光学系の開口数と投影光学系の開口数との比（σ値）を０．５としているので、投影像は明暗コントラストがほとんど無い平坦な光強度分布をもつことが判る。

図１３は、図７の参考例において開口絞り６Ａの孔を比較的大きく、照明光学系の開口数と投影光学系の開口数との比、いわゆるσ値を０．９とした場合の基板上の投影像の光強度分布を示している。ここでは、照明光学系の開口数と投影光学系の開口数との比（σ値）を０．９としているので、図１２の場合よりも投影像の明暗コントラストがついているが、やはり０次回折光成分が比較的多い依然として平坦に近い光強度分布となっており、レジストの感光特性からみて不充分であることが判る。

図１４は、図９の別の参考例の場合の基板上の投影像の光強度分布を示しており、この場合、空間フィルタ６Ｂの円環状の透光窓の内縁はσ値で０．７、外縁はσ値で０．９に相当している例である。この投影像は、図１２の場合よりも明暗コントラストがついたものとなっているが、やはり０次回折光成分が比較的多い依然として平坦に近い光強度分布となっており、レジストの感光特性からみて不充分であることが判る。

図１１～図１４に明らかなように、図７や図９の場合と比較して、図２に示した本発明の実施例では基板上の投影像の実質的な解像度が大幅に向上している。

ところで、図９の場合において、投影光学系１３のフーリエ変換面１４に前述の図２の実施例において使用した空間フィルタ１５と同様な空間フィルタを同様に配置すれば、図１０でクロスハッチで示される部分に０次および±１次の回折光を選択的に集光させて、ウェハ１７上における投影像の解像度を図１４の場合よりも少しだけ向上させることは可能である。しかしながらこの場合、投影光学系に入射される照明光の利用率が大幅に低下し、露光に寄与しないエネルギー成分が投影光学系内に蓄積されてその光学特性を変化させる欠点が不可避である。本発明に従った図２の実施例では投影光学系へ入射される照明光の殆どのエネル

ギーが露光に寄与する。

さて、従来においても、マスクパターンにおける回折光を積極的に利用して投影光学系の解像度を向上する技術があり、これは、パターンの光透過部の１つおきに照明光の位相を反転させる誘電体、いわゆる位相シフターを設ける技術である。しかしながら、複雑な半導体回路パターン上に位相シフターを適切に設けることは現実には極めて難しく、位相シフター付フォトマスクの検査方法も未だに確立されていない。

本願発明に従った前記図２の実施例における投影像の解像度向上の効果は、位相シフターのそれに匹敵するものでありながら、位相シフターをもたない従来のフォトマスクがそのまま使用でき、従来のフォトマスク検査技術もそのまま踏襲することができるものである。

また、位相シフターを採用すると投影光学系の焦点深度が実質的に増大する効果も得られるが、図２の実施例においても、図６に示されるとおり、フーリエ変換面１４でのスポット２２ℓ、２２ｒは瞳の中心から等距離の位置にあり、従って先に述べたようにデフォーカスによる波面収差の影響を受けにくく、深い焦点深度が得られるものである。

尚、前述の実施例では、マスクパターンとしてｘ方向に規則的な変化を示すライン・アンド・スペース・パターンを例示したが、以上の効果はライン・アンド・スペース以外の一般的なパターンについても、それぞれ適正な空間フィルタを組合せることにより、十分に達成される。ここで、マスクパターンの変化がｘ方向のみの１次元の変化をもつ場合には空間フィルタ上の透光窓は２個であるが、複数のｎ次元の変化をもつパターンの場合は、パターンの空間周波数に応じて２ｎ個の透光窓を持つことになる。例えばｘおよびｙ方向の２次元の変化をもつ回折格子状パターンでは、図５ｂに示したように十字線上に配置した２対、計４個の透光窓を空間フィルタに形成すればよく、これによって図６ｂに示したように対応した４つの回折光スポットが投影光学系のフーリエ変換面に形成される。

また前述の実施例では、説明を簡略化するために、空間フィルタの遮光部は照明光を全く透過させないものとして扱ってきたが、これを或る定められた光透過

率をもつ減光部として構成してもよく、その場合は、従来と同様の照明光の前光束断面による露光に際して、特定の微細パターンについてのみ、その投影像のコントラストを選択的に向上させることが可能となる。

更に前述の実施例では、特に照明光学系中の空間フィルタを中心に説明を行ったが、投影光学系中の空間フィルタについても作用および効果は基本的に同様なものと考えることができる。つまり、照明光学系のほぼフーリエ変換面と、投影光学系のほぼフーリエ変換面との少なくとも一方に上記条件を満足する空間フィルターを配置すれば、同様の効果を得ることができる。また、例えば、照明光学系のフーリエ変換面に図３に示したような空間フィルタを設けるとともに、投影光学系のフーリエ変換面に円環状の透光窓を備えた空間フィルタを配置してもかまわない。なお、この場合、後者の円環状の透光窓を備えた空間フィルタにおいては、マスクパターンからの０次回折光と＋１次（または－１次）回折光とがともに透過するように円環状の透光窓を配置することが必要であることは言うまでもない。また、両方の空間フィルタを併用することにより、投影光学系またはウェハによる乱反射光をカットし、迷光を防止する効果もある。

更にまた前述の実施例では、空間フィルタ（６、１５）をマスクパターンに応じて機械的に交換場合を主に説明したが、例えば液晶表示素子やＥＣ（エレクトロクロミック）素子等を用いた空間フィルタを採用した場合には機械的なフィルタ交換機構が不要になると共に、透光窓の位置調整と変更が電気回路装置によって達成でき、装置まわりがコンパクトになるとともに、透光窓の大きさと形状、位置の調整や変更等が簡単に、しかも高速に行えるようになるといった利点がある。

以上に述べた各実施例は限定を意図しない例示を目的とするものであり、本発明の技術的範囲は添付の請求の範囲各項の記載の基いて定められるべきである。

請求の範囲

1．マスクに照明光を照射する照明光学系と、この照明されたマスクの微細パターンの像を基板上に投影するための投影光学系とを有する投影露光装置を使用してマスクの微細パターンを基板上に転写する露光方法であって、

前記照明光を前記マスクに対して傾けて照射し、それによって照明されたマスクの微細パターンから生じる±１次回折光のいずれか一方と０次回折光とが前記マスクの微細パターンに対する前記投影光学系中のフーリエ変換面またはその近傍において前記投影光学系の光軸から互いに等距離だけ離れて通過するようにする露光方法。

2．前記±１次回折光のいずれか一方と０次回折光とを除く光を基板へ到達しないように制限する請求項１による露光方法。

3．マスクに照明光を照射する照明光学系、

この照明されたマスクの微細パターンの像を基板上に投影するための投影光学系、および

前記マスクの前記微細パターンに対する前記照明光学系および／または前記投影光学系中のフーリエ変換面もしくはその近傍位置に配置され、それが配置された前記照明光学系および／または前記投影光学系の光軸から離れた位置に周囲よりも比較的高い光透過率をもつようにそれぞれ独立した限定領域によって画定された少なくとも２つの窓手段を有する空間フィルタ手段、

を備えた、マスクの微細パターンを基板上に投影するための露光装置。

4．請求項３による露光装置において、前記空間フィルタ手段はそれが配置された前記照明光学系および／または前記投影光学系の光軸に対して対称な対をなす２つの窓手段を含むもの。

5．請求項３による露光装置において、前記空間フィルタ手段が２ｎ個（ｎは自

然数）の窓手段を有するもの。

6．請求項３による露光装置において、前記空間フィルタ手段が、前記微細パターンのフーリエ変換パターンに基いて定められた複数の位置に前記窓手段を有するもの。

7．請求項３による露光装置において、前記照明光学系がフライアイレンズ等のオプチカルインテグレータを備え、前記空間フィルタ手段が前記オプチカルインテグレータの射出端近傍位置に配置されたもの。

8．請求項３による露光装置において、前記空間フィルタ手段の前記窓手段を除く部分が遮光部に形成されているもの。

9．請求項３による露光装置において、前記空間フィルタ手段の前記窓手段を除く部分が減光部に形成されているもの。

10．請求項３による露光装置において、前記空間フィルタ手段が前記照明光学系中に配置され、その各窓手段の位置は、前記微細パターンから発生する±１次回折光のいずれか一方と０次回折光とが前記マスクの微細パターンに対する前記投影光学系中のフーリエ変換面において前記投影光学系の光軸からほぼ等距離だけ離れて別々に通過するように定められているもの。

11．請求項４による露光装置において、前記空間フィルタ手段が前記照明光学系中に配置され、前記対を構成する第１の窓手段およびそれに光軸対称な第２の窓手段の各位置は、第１の窓手段を通過して前記マスクへ至る照明光束の照射によって前記微細パターンから発生する±１次回折光のいずれか一方と０次回折光との二つの回折光束と、第２の窓手段を通過して前記マスクへ至る照明光束の照射によって前記微細パターンから発生する±１次回折光のいずれか一方

と０次回折光との二つの回折光束とが、前記投影光学系のフーリエ変換面において投影光学系の光軸からほぼ等距離で離れた別々の第１と第２の光路を交互に、即ち、第１の窓手段からの照明光による±１次回折光のいずれか一方と第２の窓手段からの照明光による０次回折光との二つの回折光束が第１の光路を通過し、第２の窓手段からの照明光による±１次回折光のいずれか一方と第１の窓手段からの照明光による０次回折光との二つの回折光束が第２の光路を通過するように定められているもの。

12. 請求項３による露光装置において、前記窓手段の前記光軸回りの角度位置および前記光軸からの間隔距離の少なくとも一方をマスクの微細パターンに対応して調整または切換えのために変える駆動手段を更に備えたもの。

13. 請求項12による露光装置において、前記空間フィルタ手段が少なくとも一対の窓手段を有する遮光または減光板素子を含み、前記駆動手段が、前記板素子を相対的に異なる位置に窓手段をもつ別の板素子と交換する機構を備えているもの。

14. 請求項12による露光装置において、前記空間フィルタ手段が少なくとも一対の任意の位置の限定領域を透明化および不透明化できる電気光学素子を含み、前記駆動手段が、この電気光学素子を前記限定領域の透明化および不透明化のために駆動する電気回路手段を備えているもの。

15. マスクに照明光を照射する照明光学系、

この照明されたマスクの微細パターンの像を基板上に投影するための投影光学系、および

前記マスクの前記微細パターンに対する前記照明光学系中のフーリエ変換面もしくはその近傍位置における前記照明光の強度分布を前記照明光学系の光軸から離れた少なくとも２つの個所で前記強度が極大となるように制限する光学

的制限手段、

を備え、前記各個所の各々の中心が前記マスクの微細パターンの微細度に従って選択された間隔だけ互いに離れている、マスクの微細パターンを基板上に投影するための露光装置。

16. 請求項15による露光装置において、前記照明光学系が、前記光学的制限手段の前記2個所からの照明光束を前記マスク上でほぼ対称的に傾ける光学要素を含むもの。

17. マスクを照明するための照明光を発生する照明手段、

前記照明光を前記マスク上で傾けるための光学要素、および

前記マスクに対してほぼ垂直な光軸を有し、傾けられた前記照明光によってマスクから生じる光により前記マスクの微細パターンの像を基板上に投影する投影光学系、

を備え、前記照明光によって前記マスクの微細パターンから生じる±1次回折光のいずれか一方と0次回折光とが前記マスクとほぼ垂直な線に関してほぼ対称的な傾斜角で前記投影光学系に入射される、マスクの微細パターンを基板上に投影するための露光装置。

18. 請求項17による露光装置において、前記照明光学系が、前記光学的制限手段の前記2個所からの照明光束を前記マスク上でほぼ対称的に傾ける光学要素を含むもの。

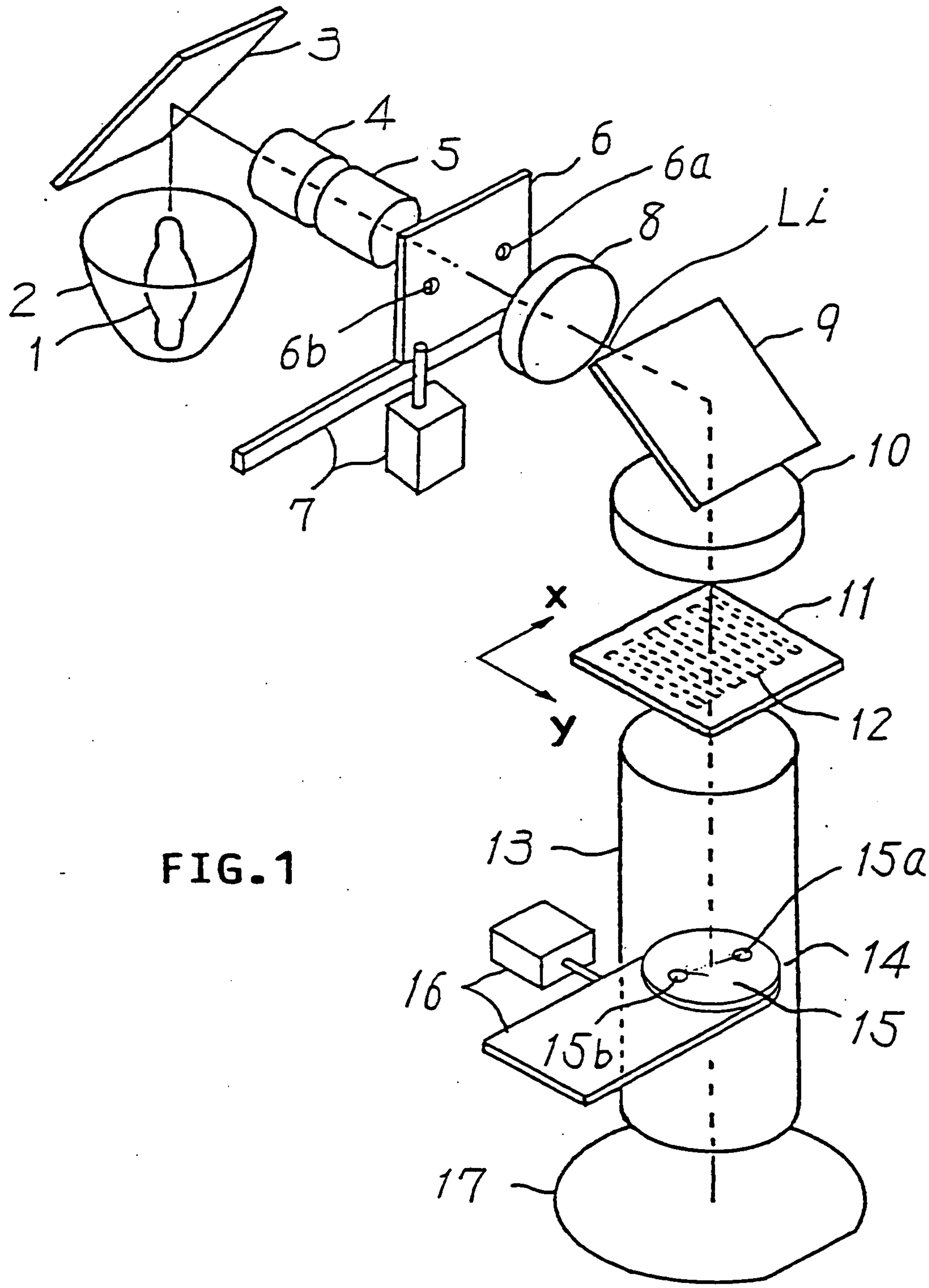

FIG.1

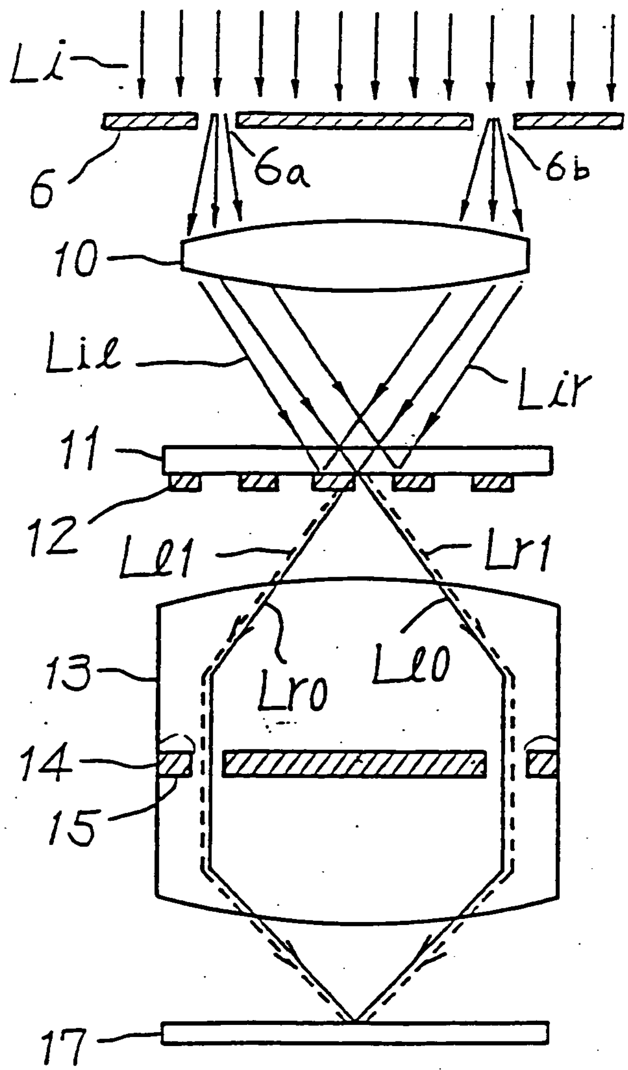

FIG.2

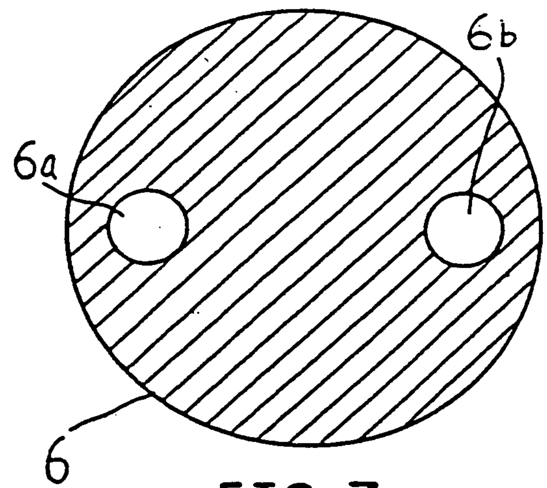

FIG.3

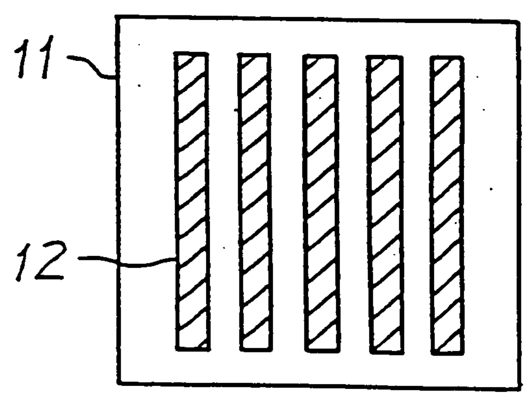

FIG.4

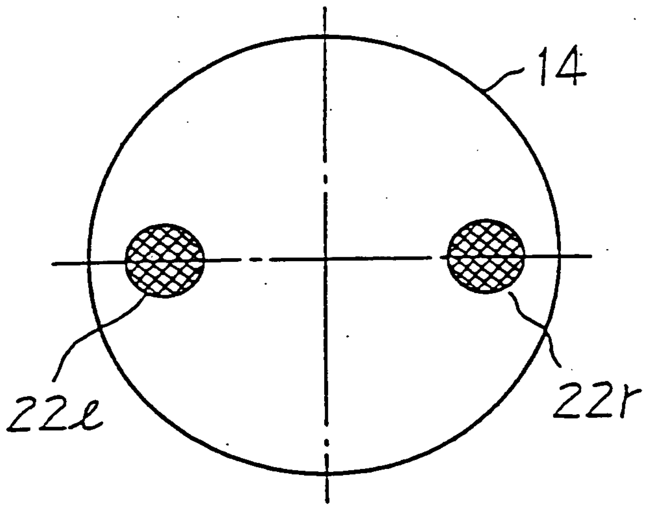

FIG.6a

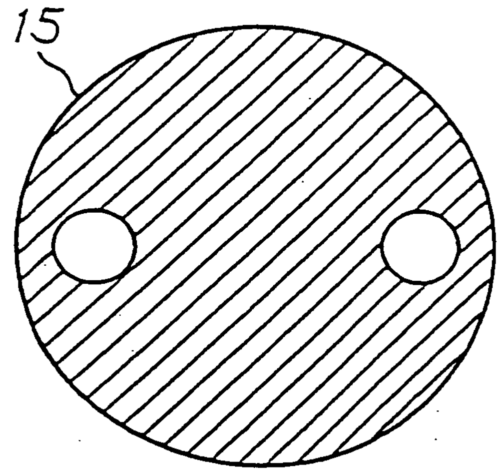

FIG.5a

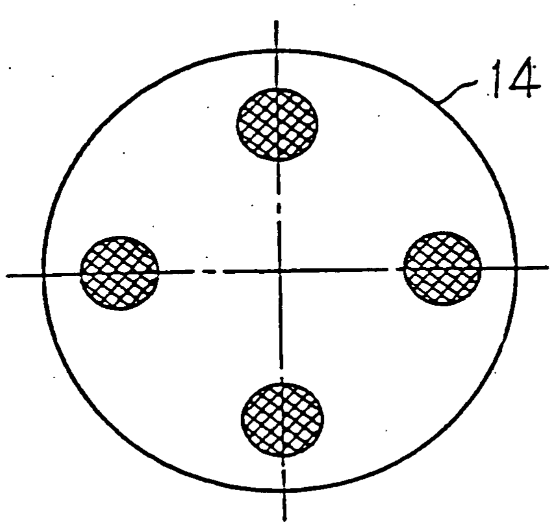

FIG.6b

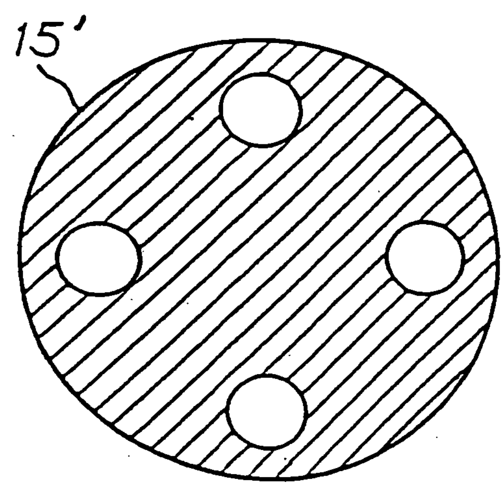

FIG.5b

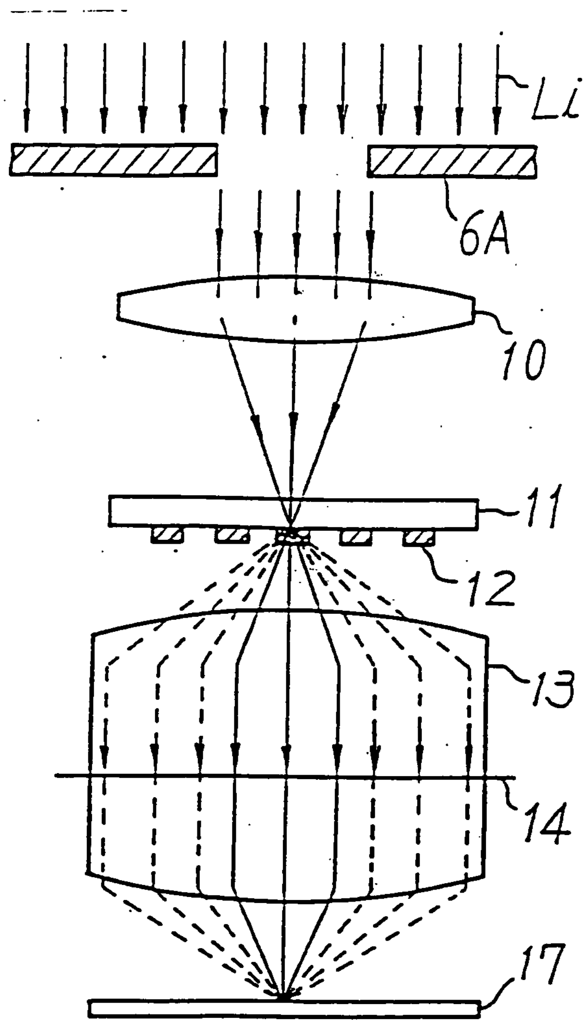

FIG.7

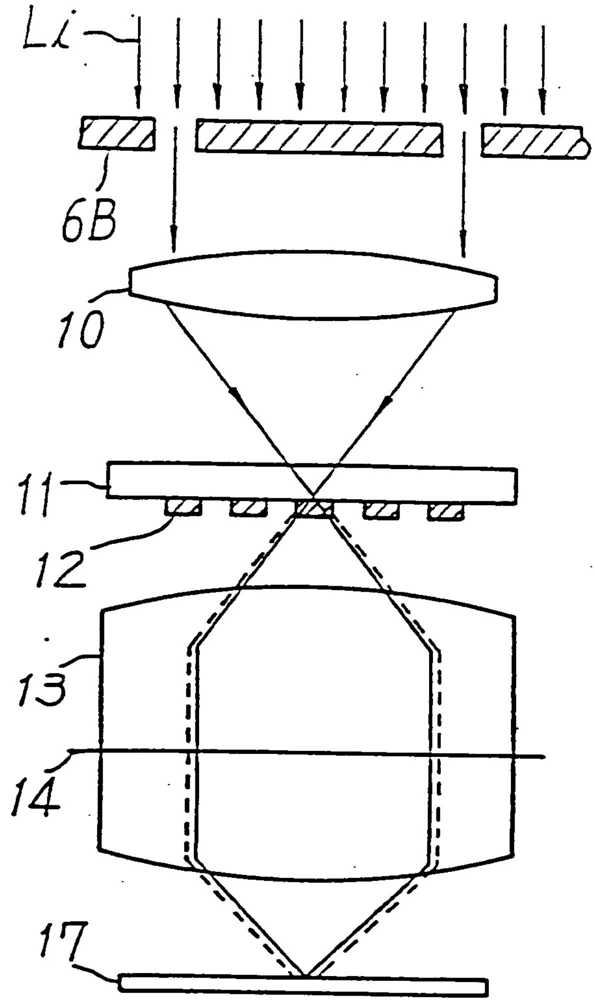

FIG.9

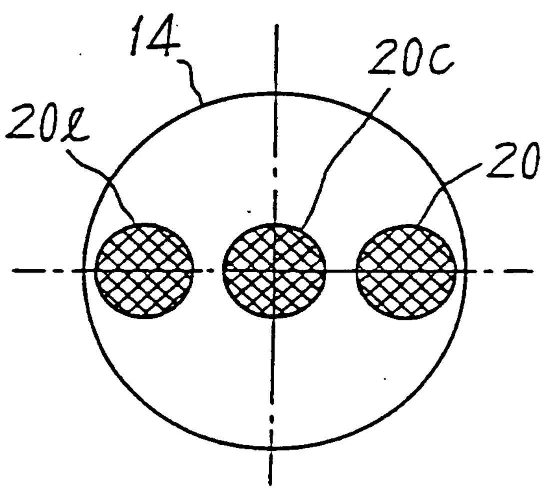

FIG.8

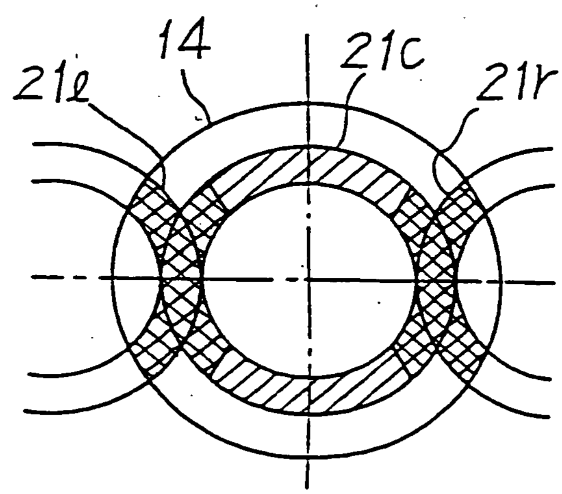

FIG.10

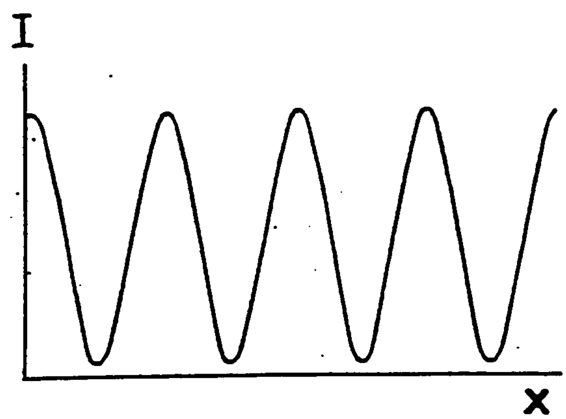

FIG.11

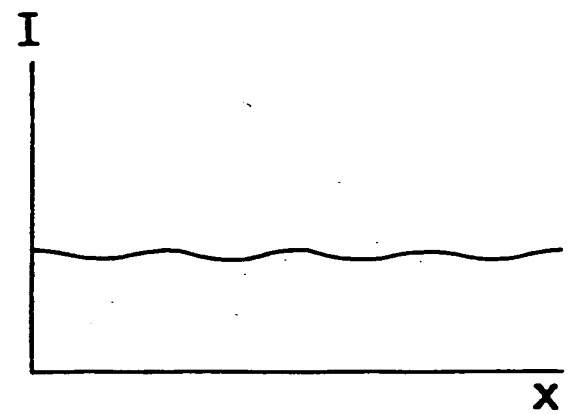

FIG.12

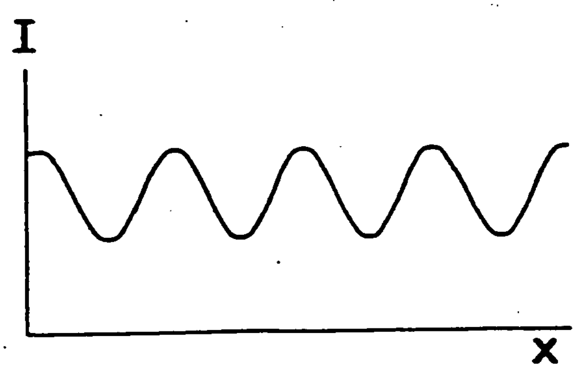

FIG.13

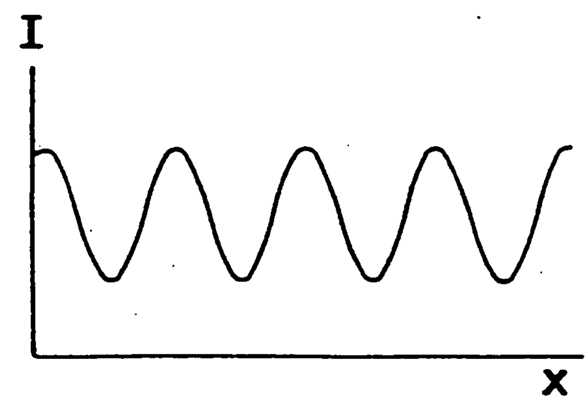

FIG.14

INTERNATIONAL SEARCH REPORT

International Application No PCT/JP91/01103

I. CLASSIFICATION F SUBJECT MATTER (If several classification symbols apply, indicate all) [6]

According to International Patent Classification (IPC) or to both National Classification and IPC

Int. Cl[5] H01L21/027

II. FIELDS SEARCHED

Minimum Documentation Searched [7]

Classification System	Classification Symbols
IPC	H01L21/027, G03F7/20

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched [8]

Jitsuyo Shinan Koho 1970 - 1991
Kokai Jitsuyo Shinan Koho 1971 - 1991

3a

III. DOCUMENTS CONSIDERED TO BE RELEVANT [9]

Category *	Citation of Document, [11] with indication, where appropriate, of the relevant passages [12]	Relevant to Claim No. [13]
A	JP, A, 59-83165 (Hitachi, Ltd.), May 14, 1984 (14. 05. 84), (Family: none)	1-18

* Special categories of cited documents: [10]

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

IV. CERTIFICATION

Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report
October 18, 1991 (18. 10. 91)	November 5, 1991 (05. 11. 91)
International Searching Authority	**Signature of Authorized Officer**
Japanese Patent Office	

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(54) **METHOD AND DEVICE FOR OPTICAL EXPOSURE.**

(57) A method and a device for transferring minute patterns (12) on the mask (11) to the substratum (17) by means of illuminating optical system (1-10) projecting beams of illuminating light onto the mask (11) and a projection aligner having a projection optical system (13) for projecting images of minute patterns (12) on the substratum (17). Beams of said illuminating light are thrown, as at least a pair of luminous fluxes slantwise facing the mask (11), through a pair of light transmitting windows (6a, 6b) of a spatial filter (6) onto the minute patterns (12), and, as a result, one of diffracted beams of the light of ± first orders caused by minute patterns (12) of the illuminated mask (11) and diffracted beams of zero order pass portions, equidistantly spaced apart from the optical axis of the projection optical system, of or near the Fourier transform surface (14) in the projection optical system (13) for minute patterns (12) on the mask (11) so that projected images may be formed to be sharp in contrast and high in resolution on the substratum (17) at a large focal depth.

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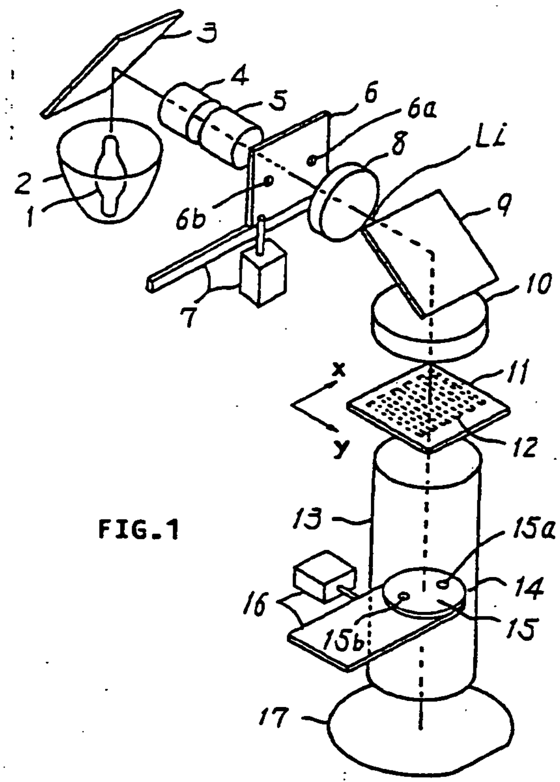

FIG.1

[Technical Field]

The present invention relates to an exposure method and apparatus and more particularly to a projection exposure method and apparatus used in the lithographic operation for such semiconductor memory devices and liquid crystal devices having regular fine patterns.

[Background Art]

In the manufacture of semiconductor memory devices and liquid crystal devices by photolithographic techniques, the method of transferring a mask pattern onto a substrate has been generally used. In this case, the illuminating light for exposure purposes, e.g., ultraviolet light is irradiated on the substrate having a photosensitive resist layer formed on its surface through a mask formed with a mask pattern and thus th mask pattern is photographically transferred onto the substrate.

The common type of the fine mask patterns for semiconductor memory devices, liquid crystal devices, etc., can be considered as regular grating patterns which are vertically or laterally arranged at equal intervals. In other words, in the mask pattern of this type the most dense pattern area is formed with a grating pattern composed of equally-spaced transparent and opaque lines which are alternately arranged in the X-direction and/or the Y-direction to realize the minimum possible line width which can be formed on the substrate and the other area is formed with a pattern of a comparatively low degree of fineness. Also, in any case any oblique pattern is exceptional.

Further, the ordinary photosensitive resist material has a non-linear light response characteristic so that the application of a light quantity greater than a certain level causes chemical changes to proceed rapidly, whereas practically the chemical changes do not progress when the quantity of light received is less than this level. As a result, there is a background that with the projected image of the mask pattern on the substrate, if the difference in light quantity between the light and dark portions is ensured satisfactorily, even if the contrast of the boundary between the light and dark portions is low more or less, the desired resist image as the mask pattern can be obtained.

With the recent tendency toward finer pattern structures for semiconductor memories and liquid crystal devices, projection exposure apparatus such as a stepper for transferring a mask pattern onto a substrate by reduction projection have been used frequently and a special ultraviolet light which is shorter in wavelength and narrow in wavelengh distribution range has also come into use as an exposure illuminating light. In this case, the reason for reducing the wavelength distribution range resides in eliminating any deterioration in the image quality of a projected image due to the chromatic aberrations of the projection optical system in the exposure apparatus and the reason for selecting the shorter wavelength is to enhance the contrast of the projected image. However, the actual situation is such that this attempt of reducing the wavelength of an illuminating light has reached the limit with respect to the requirements for finer mask patterns, e.g., the projection exposure of line windth of the submicron order due to the non-existence of any suitable light source, the restrictions to lens materials and resist materials, etc.

In the case of such a finer mask pattern, the required value for the resolution (line width) of the pattern approaches the wavelength of the illuminating light so that the effect of the diffracted light produced by the transmission of the illuminating light through the mask pattern is not ignorable and it is difficult to ensure a satisfactory light-and-dark contrast of the projected mask pattern image on the substrate, thereby particularly deteriorating the light-and-dark contrast of the line edges of the pattern.

In other words, while the diffracted beams of the 0-order, ± first-orders, ± second-orders and higher-orders produced at various points on the mask pattern by the illuminating light incident on the mask from above are respectively reconverged at the corresponding conjugate points on the substrate for imaging through the projection optical system, the diffracted beams of the ± first-orders, ± second-orders and higher-orders are further increased in diffraction angle as compared with the diffracted beam of the 0-order and are incident on the substrate at smaller angles for the finer mask pattern, thus giving rise to a problem that the focus depth of the projected image is decreased greatly and a sufficient exposure energy is supplied only to a portion of the thickness of the resist layer.

As a measure for coping with such decrease in the focus depth, Japanese Laid-Open Patent Application No. 2-50417 (laid open on February 20, 1990) discloses the method of arranging an aperture stop concentrically with the optical axis of each of an illumination optical system and a projection optical syst m to restrict the angl s of incidenc of an illuminating light on a mask and adjusting the opening diamet rs of the aperture stops in accordanc with a mask pattern, thereby ensuring th focus depth while maintaining the light-and-dark contrast of a proj cted image on a sample substrate. Even in the cas of this known method, how ver, the diffraction angles of diffracted beams of the ± first-ord rs and high r-orders ar still

large as compared with a 0-order diffracted beam reaching substantially vertically to the surface of a substrate and practically all of them come out of the field of view of a projection lens, thereby producing on the substrate only a projected mask pattern image composed by substantially only the 0-order beam component and having a weak contrast.

Also, while, in this case, there is the possibility of a part of the ± first-order diffracted beams coming within the field of view of the projection lens and reaching the substrate, in contrast to the 0-order diffracted beam incident substantially vertically on the substrate, the part of the ± first-order diffracted beams is incident on the substrate at a smaller angle and therefore it is pointed out that a satisfactory focus depth is still not obtainable.

On the other hand, U.S. Patent No. 4,947,413 granted to T. E. Jewell et all discloses a lithography system in which an off-axis illumination light source is used and an interference the 0-order diffracted beam and only one of the ± first-order beams from a mask pattern is made possible by use of a spatial filter processing in the Fourier transform plane within a projection optical system, thereby forming a high-contrast projected pattern image on the substrate with a high degree of resolution. With this system, however, the illumination light source must be arranged in an off-axis position in which it is obliquely directed to the mask, and also due to the fact that the 0-order diffracted beam and only one of the ± first-order diffracted beams are simply caused to interfer with each other, the dark-and-light contrast of the edges in the pattern image resulting from the interference is still unsatisfactory due to the unbalanced light quantity difference between the 0-order diffracted beam and the first-order diffracted beam.

[Disclosure of Invention]

It is an object of the present invention to provide a projection exposure method and apparatus so designed that a projected image having a sufficient light-and-dark contrast is produced with a large focus depth on a substrate from the fine mask pattern of the ordinary mask having no phase shifting means, and more particularly it is an object of the invention to positively utilize the fact that the illuminating light has a narrow wavelength distribution, that the mask pattern can be substantially considered to be a diffraction grating, that the resist material has a non-linear light responsive characteristic for the amount of light received and so on as mentioned previously so as to form a resist image of a finer mask pattern for the same wavelength of the illuminating light.

In accordance with a basic idea of the present invention, when using an exposure apparatus including an illumination optical system for illuminating a mask formed at least partially with a fine pattern with an illuminating light and a projection optical system for projecting an image of the illuminated fine pattern on a substrate so as to transfer the fine pattern of the mask on the substrate, the illuminating light is directed from at least two locations to fall on the mask with given angles of incidence in an obliquely opposing manner so that the 0-order diffracted beam and either one of ± first-order diffracted beams produced from the fine pattern by each of the obliquely illuminating beams are respectively passed through optical paths which are substantially equidistant from the optical axis of the projection optical system at or in the vicinity of the Fourier transform plane within the projection optical system with respect to the fine pattern on the mask, thereby forming on the substrate a projected image of the fine pattern principally by either of the ± first-order diffracted beams and the 0-order diffracted beam. In this case, the other undesired beams excluding either of the ± first-order diffracted beams and the 0-order diffracted beam do not substantially reach the substrate. As optical means for this purpose, principally spatial filter means is arranged in the illumination optical system and/or the projection optical system. Also, the illumination optical system can be constructed so as to direct the illuminating light along its optical axis and the illumination optical system includes an optical element, e.g., condenser lens means arranged on this side of the mask such that the illuminating light falls at the given angles of incidence on the mask.

An exposure apparatus according to a preferred aspect of the present invention includes an illumination optical system for irradiating an illuminating light on a mask, a projection optical system for projecting an image of the fine pattern on the illuminated mask onto a substrate and spatial filter means arranged at or in the vicinity of the Fourier transform plane within the illumination optical system and/or the projection optical system with respect to the fine pattern on the mask, and the spatial filter means includes at least two window means which are each defined by an independent limited area having a comparatively higher light transmittance than the surrounding at a position apart from the optical axis of the illumination optical system and/or the projection optical system in which it is arranged. The Fouri r transform plane at which the spatial filter means is arranged is placed for example in a position that is practically in the pupil plane of the illumination optical system, the conjugate plane to the aforesaid pupil plane or th pupil plane of the projection optical system, and the spatial filter means can be arranged at least in on of thes positions.

In accordanc with another preferred aspect of the present invention, the spatial filter m ans includes the two window means at substantially the symmetric positions with the optical axis of the illumination optical system and/or the projection optical system in which it is arranged.

In accordance with another preferred aspect of the present invention, the number of the window means in the spatial filter means is 2n (n is a natural number). Also, the window means is preferably arranged at each of a plurality of positions determined in accordance with the Fourier transform pattern of the fine pattern.

In accordance with another aspect of the present invention, the illumination optical system includes an optical integrator, e.g., fly-eye lenses and in this case the spatial filter means is arranged in a position near to the exit end of the optical integrator.

In accordance with the present invention, the portion of the spatial filter means excluding the window means is generally formed as a dark portion or a light shielding portion whose light transmittance is substantially 0% or so or alternatively it is formed as a light attenuating portion having a predetermined light transmittance which is lower than that of the window means.

In accordance with another aspect of the present invention, the spatial filter means is arranged within the illumination optical system and the positions of its window means are selected such that either one of the ± first-order diffracted beams and the 0-order diffracted beam due to each window means are respectively passed through positions which are practically apart by the equal distance from the optical axis of the projection optical system at or in the vicinity of the Fourier transform plane within the projection optical system with respect to the fine pattern on the mask.

In accordance with another preferred aspect of the present invention, the spatial filter means is arranged within the illumination optical system and the spatial filter means includes first and second window means forming a symmetrical pair with respect to the optical axis of the illumination optical system, with the positions of the first and second window means being so determined that the two diffracted beams, i.e., either one of the ± first-order diffracted beams and the 0-order diffracted beam produced from the fine pattern by the irradiation of the illuminating light beam reaching the mask through the first window means and another two diffracted beams, i.e., either one of the ± first-order diffracted beams and the 0-order diffracted beam produced from the fine pattern by the irradiation of the illuminating light beam reaching the mask through the second window means are alternatively passed through separate first and second optical paths which are apart by practically the equal distance from the optical axis of the projection optical system at or positions near to the Fourier transform plane within the projection optical system, that is, the two diffracted beams, i.e., either one of the ± first-order diffracted beams due to the illuminating light from the first window means and the 0-order diffracted beam due to the illuminating light through the second window means are for example passed through the first optical path and either one of the ± first-order diffracted beams due to the illuminating light through the second window means and the 0-order diffracted beam due to the illuminating light through the first window means are for example passed through the second optical path.

In accordance with another preferred aspect of the present invention, the exposure apparatus includes drive means for varying at least one of the angular positions of the window means about the optical axis and their distance apart from the optical axis in accordance with the fine pattern on the mask for adjusting or switching purposes. Where the spatial filter means comprises a light shielding plate or light attenuating plate including a plurality of window means, the drive means comprises a mechanism for replacing the light shielding plate or the light attenuating plate with one having window means at different positions, whereas if the spatial filter means comprises an electrooptic element which is capable of making transparent or opaque the limited areas at arbitrary positions, such as, a liquid crystal device or an electro chromic device, the drive means comprises electric circuit means for driving the electrooptic element for the purpose of making the limited areas transparent or opaque.

The conventional projection exposure apparatus uses indiscriminately an illuminating light which falls at various angles of incidence on a mask from above so that the respective diffracted beams of the 0-order, ± first-orders, ± second-orders, and higher-orders produced from the mask pattern are directed in practically disordered directions and the positions at which these diffracted beams are imaged through the projection optical system on a substrate are different from one another. On the contrary, the projection exposure apparatus of the present invention selectively uses the illuminating light which is incident on a mask pattern with specified directions and angles from th given positi ns within a plane inters cting th optical axis at right angl s so that either one of th ± first-order diffracted beams and the 0-ord r diffracted beam produced from the mask pattern by each illuminating beam are mainly directed onto the substrate and chiefly participate in the formation of a proj cted image of the fine patt rn on the substrate. In other words, in accordance with the present invention the spatial filt r means corr sponding to the mask pattern is used

for this purpose so that only optimum one of the ± first-order diffracted beams and the 0-order diffracted beam by each illuminating beam are mainly selected from the illuminating light by the spatial filter means and are directed onto the substrate, thereby forming on the substrate a projected pattern image which is higher in the light-and-dark contrast of the edges of the fine pattern than previously and which is large in focus depth.

In this connection, there are the following two methods for the application of the spatial filter means according to the present invention. More specifically, the first method is such that the illuminating light is intercepted or attenuated at a portion of its beam cross-section on this side of the mask so as to select, as the principal illuminating light, the illuminating light obliquely incident with the specified direction and angle from each of the given positions within the plane intersecting the optical axis at right angles, and for this purpose the spatial filter means is arranged at the Fourier transform plane within the illumination optical system or a position rear thereto. The second method is such that of the various diffracted beam components produced from the mask pattern illuminated by the illuminating light of various angles of incidence, the two component beams or either one of the ± first-order diffracted beams and the 0-order diffracted beam produced from the mask pattern by each of the illuminating beams incident obliquely with the given directions and angles from the given positions within the plane intersecting the optical axis at right angles are selected within the projection optical system, and for this purpose the spatial filter means is arranged at the Fourier transform plane within the projection optical system or a position near thereto. These first and second methods may be used in combination and in any way the spatial filter means serves the role of limiting the light beams participating in the formation of a projected pattern image on the substrate to either one of the ± first-order diffracted beams and the 0-order diffracted beam produced from the mask pattern by each of the illuminating beams which are incident obliquely with the specified inclination angles and preventing the other undesired beams from reaching the substrate.

Where the spatial filter means is arranged at the Fourier transform plane within the illumination optical system or a position near thereto, the illuminating light having a given wavelength is projected onto the mask pattern in the form of a diffraction grating with the given angles of incidence from the given eccentric positions in the given angular directions about the optical axis so that theoretically a series of spots due to the Fourier expanded 0-order, first-orders, second-orders and higher-orders diffracted beams are formed at the Fourier transform plane of the projection optical system or positions near thereto. In the conventional projection exposure apparatus, however, the second-orders and higher-orders diffracted beams are eclipsed by the lens tube of the projection optical system.

The spatial filter means arranged at the Fourier transform plane within the illumination optical system or a position near thereto is also designed so that the illuminating light falling substantially vertically on the mask is intercepted or attenuated and that the illuminating light to be incident on the mask at the given angles of inclination from the given eccentric positions in the given angular directions about the optical axis is selectively passed with a high light transmittance. In this case, if the diffracted beams of the second-orders and higher-orders are not desired, another spatial filter means is further provided at the Fourier transform plane within the projection optical system or in the vicinity thereof to block or attenuate these beams. As a result, a high-contrast projected pattern image is formed on the substrate by the 0-order diffracted beam and the first-order diffracted beams produced from the mask pattern by the illuminating light at the preferred angles of incidence.

Then, with the mask patterns for semiconductor memory devices and liquid crystal devices, there are many cases where the portion of the mask pattern requiring a high-resolution transfer has a pattern composed of a grating pattern in which basically equispaced transparent and opaque lines are regularly arranged alternately and this can be generally considered to be a repetition pattern of rectangular waveforms at the duty ratio of 0.5. Where the spatial filter means is arranged at the Fourier transform plane within the illumination optical system or a position near thereto, due to the diffracted beams produced from the grating pattern, a series of spots of the diffracted beams of the 0-order, ± first-orders, ± second-orders and higher-orders are formed at the Fourier transform plane of the projection optical system so as to be distributed in the direction of traversing the lines of the grating (the direction in which the lines are arranged). At this time, in the like manner known as the ordinary Fourier expansion of a rectangular wave, the 0-order diffracted beam provides a reference level for the light quantity in the projected image on the substrate and the ± first-order diffracted beams are the light quantity variation components of the sinusoidal wav form having th same period as the grating, so that when these diffracted beam components are condensed on the substrate, the interference of these diffracted beams produces on the substrate an imaged pattern having a sufficient light quantity for the sensitization of the r sist lay r and a high light-and-dark contrast.

Also, in this case the ordinary mask pattern for semiconductor memory d vices and liquid crystal

devices can be considered to be a combination of a plurality of gratings which are respectiv ly arranged vertically or traversely on the mask so that if spatial filter means is prepared so as to ensure illuminating light beams having the optimum eccentric positions in the angular directions about the optical axis and the optimum angles of incidence for each grating, the resulting Fourier pattern formed at the Fourier transform plane of the projection optical system forms a spot group arranged in the angular directions corresponding to the line arranging directions of the gratings and having the spacings corresponding to the wavelength of the illuminating light and the line pitches of the gratings. The light intensity of each spot is dependent on the number of pitches of the gratings and the orders of the diffracted beams.

As will be seen from this fact, the same effect can be obtained by arranging within the projection optical system spatial filter means formed with window means only at the positions corresponding to the required spot positions so as to select the diffracted beams directed to the substrate. In this case, the spatial filter means arranged at the Fourier transform plane or a position near thereto includes the window means at the spot positions of the useful diffracted beams in the Fourier transform plane so that the useful diffracted beams are selectively passed while blocking the undesired diffracted beams which cause deterioration of the contrast at the substrate surface.

Thus, the number and positions of the windows in the spatial filter means inherently differ depending on the mask pattern so that when the mask is changed, the spatial filter means is also changed in company therewith as a matter of caurse and moreover it must be exactly adjusted in position relative to the mask.

Next, a description will be made of the reason why the focus depth is increased by projecting the illuminating light beams of the given angles of incidence onto the mask pattern from the given eccentric positions in the given angular directions about the optical axis and forming an imaged pattern on the substrate by means of either one of the ± first-order diffracted beams and the 0-order diffracted beam produced from the mask pattern by each of the illuminating light beams.

Generally, where the substrate is in registration with the focal position of the projection optical system, the diffracted beams of the respective orders which emerge from one point on the mask and reach one point on the substrate are all equal in optical path length irrespective of the portions of the projection optical system through which they pass so that even in cases where the 0-order diffracted beam passes through practically the center of the pupil plane of the projection optical system, the 0-order diffracted beam and the diffracted beams of the other orders are equal in optical path length and, with the optical path length of the light beam passing parctically the center of the Fourier transform plane being taken as a reference, the difference between the optical path length of the light beam passing through any arbitrary position of the Fourier transform plane and the reference optical path length or the front wave aberration is zero. Where the substrate is in a defocus position which is not in registration with the focal position of the projection optical system, however, the optical path length of the diffracted beam having any of the first and higher orders and passing any closer-to-outer-periphery portion of the Fourier transform plane within the projection optical system to fall obliquely on the substrate is decreased as compared with the 0-order diffracted beam passing through near the center of the Fourier transform plane when the substrate is positioned before the focal point and the amount of defocus is negative, whereas it is increased when the substrate is positioned in the rear of the focal point and the amount of defocus is positive; this difference in optical path length has a value corresponding to the difference in angle of incidence on the substrate between the diffracted beams of the respective orders and this is referred to as the front wave aberration due to the defocus. In other words, due to the presence of such defocus, each of the diffracted beams of the first and higher orders causes a front wave aberration with respect to the 0-order diffracted beam and the imaged pattern in either the front or the rear of the focal point is blurred. This front wave aberration ΔW is given by the following equation

$$\Delta W = 1/2 \times (NA)^2 \cdot \Delta f$$

where

Δf = the amount of defocus

NA = the value of the distance from the center in the Fourier transform plane given in terms of the numerical aperture.

As a result, in relation to the 0-order diffracted beam ($\Delta W = 0$) passing through practically the c nter of the Fourier transform plane, the first-order diffracted beam passing through th position of a radius r_1 near the outer periphery of th Fourier transform plan has the following front wave aberration

$$\Delta W = 1/2 \times r_1^2 \times \Delta f.$$

and the presence of this front wave aberration is the cause of deterioration of the resolution before and behind the focal position and reduction in the focus depth in the conventional techniques.

On the contrary, in the exposure apparatus of the present invention the spatial filter means is arranged such that either one of the ± first-order diffracted beams and the 0-order diffracted beam produced from the mask pattern by each of the illuminating light beams of the given angles of incidence are respectively passed through the eccentric positions (having the same eccentric radius r_2) of substantially the central symmetry in the Fourier transform plane within the projection optical system. As a result, in the case of the exposure apparatus of the present invention the front wave aberrations caused by the 0-order diffracted beam and the first-order diffracted beams before and behind the focal point of the projection optical system are both given as follows :

$$\Delta W = 1/2 \times r_2^2 \Delta f$$

and they are equal with each other. Thus, there is no deterioration (blur) of the image quality caused by the front wave aberrations due to the defocus, that is, the correspondingly increased focus depth is obtained.

On the other hand, where the spatial filter means is arranged within the illumination optical system, a pair of the illuminating light beams passed through the pair of the window means symmetric with the optical axis take the form of light beams which are incident on the mask surface obliquely and symmetrically on both side of the normal so that each one of the ± first-order diffracted beams produced from tee grating pattern on the mask by these light beams passes a position which is symmetric with the 0-order diffracted beam with respect to the optical axis of the projection optical system and falls on the substrate at an angle of incidence as large as that of the 0-order diffracted beam. As a result, the substantial numerical aperture of the projection optical system participating in the imaging is reduced thereby ensuring a greater focus depth.

Thus, in accordance with the present invention, by virtue of the fact that the spatial filter means having the windows of the paired structure on both side of the optical axis is used such that of the diffracted beams produced from the fine pattern on the mask by the illuminating light beams of the preferred angles of incidence the diffracted beams of the preferred orders, i.e., the 0-order diffracted beam and the first-order diffracted beams are selectively condensed at the same position on the substrate so that even in the case of such fine pattern which has never been resolved in the past, it is now possible to ensure a satisfactory light-and-dark contrast and a satisfactorily large focus depth for sensitizing the resist layer in the imaged pattern on the substrate without any change of the illuminating light and the projection optical system.

Where the spatial filter means is arranged within the illumination optical system, the spacing between the pair of windows in the spatial filter means is such that either one of the ± first-order diffracted beams produced from the fine grating pattern of the mask by the illuminating light passing through one of the windows and the 0-order diffracted beam produced by the illuminating light passing through the other window are passed through substantially the same eccentric position in the Fourier transform plane of the projection optical system.

Where the spatial filter means is arranged within the projection optical system, the spacing between the pair of windows in the spatial filter means is determined in such a manner that either one of the ± first-order diffracted beams and the 0-order diffracted beam produced from the fine grating pattern of the mask by each of the illuminating beams of the said preferred angles of incidence are respectively passed through separate eccentric positions.

In accordance with the exposure apparatus of the present invention, a suitable adjusting mechanism is used so that the spatial filter means is rotated through a certain angle or parallelly moved within the plane of its arrangement so as to compensate for the shifts in the positions of the windows of the spatial filter means relative to the mask pattern. Also, the spacing between the pair of windows may be constructed so as to be adjustable to conform more satisfactorily with the Fourier pattern of the mask pattern. In this case, by constructing so that the positions of the windows in the spatial filter or the spacing between the windows can be varied by the adjusting mechanism, it is possible to obtain the optimal positional relation between the mask and the windows of the spatial filter and also it is possible to use the same spatial filter in common with other masks containing different patterns.

In accordance with another aspect of the present invention, a spatial filter incorporating an lectrooptical element such as a liquid crystal device or an lectro chromic device is employed so that th adjustm nt of the positions and size of its windows can be effected by means of electric signals. In this case, due to the fact that the limited areas at the arbitrary positions of the spatial filter composed of the electrooptical element can be freely adjusted to become transparent or opaque, it is possible to obtain the optical positional relation between the mask pattern and the windows of the spatial filter and in this case it is of

course possible to use the same spatial filter in common with other masks containing different patterns.

In order to facilitate the understanding of the above and other features and advantages of the present invention, some preferred embodiments of the invention will be described hereunder with reference to the accompanying drawings.

[Brief Description of Drawings]

Fig. 1 is a perspective view showing the construction of an exposure apparatus according to an embodiment of the present invention,

Fig. 2 is a schematic diagram showing an optical path construction for explaining the principle of the embodiment of Fig. 1,

Fig. 3 is a plan view showing an example of the spatial filter arranged within the illumination optical system of the exposure apparatus according to the embodiment of Fig. 1,

Fig. 4 is a schematic plan view showing an example of the mask pattern,

Figs. 5a and 5b are schematic plan views showing respectively another examples of the spatial filter,

Figs. 6a and 6b are diagrams showing schematically the light intensity distributions of the diffracted beams at the Fourier transform plane of the projection optical system in correspondence to Figs. 5a and 5b, respectively,

Fig. 7 is a schematic diagram showing the optical path construction of a projection exposure apparatus according to a reference example,

Fig. 8 is a diagram showing schematically the intensity distribution of the diffracted beams at the Fourier transform plane of the projection optical system in Fig. 7,

Fig. 9 is a schematic diagram showing the optical path construction of a projection exposure apparatus according to another reference example,

Fig. 10 is a diagram showing in a schematic diversified form the intensity distribution of the diffracted beams at the Fourier transform plane of the projection optical system in the reference example of Fig. 9,

Fig. 11 is a graph showing the light quantity distribution of the projected image in the embodiment of the present invention,

Fig. 12 is a graph showing the light quantity distribution of the projected image in the reference example of Fig. 7 (where σ = 0.5),

Fig. 13 is a graph showing the light quantity distribution of the projected image in the reference example of Fig. 7 (where σ = 0.9), and

Fig. 14 is a graph showing the light quantity distribution of the projected image in the reference example of Fig. 9.

[Best Mode for Carrying Out the Invention]

In the Embodiment shown in Fig. 1, a mask 11 is formed with a one-dimensional grating pattern 12 having a duty ratio of 0.5 as a typical exemplary fine pattern. An illumination optical system for illuminating the mask 11 includes a mercury vapor lamp 1, an ellipsoidal mirror 2, a cold mirror 3, a condensing optical element 4, an optical integrator element 5, a relay lens 8 (a pupil relay system), a mirror 9 and a condenser lens 10, and a spatial filter 6 is arranged at the Fourier transform plane of the illumination optical system or in the vicinity of the exit end of the integrator element 5 where the secondary light source image of the mercury vapor lamp 1 is formed (in other words, the pupil plane of the illumination optical system or its conjugate plane or any position near thereto). The spatial filter 6 is formed with a pair of transparent windows 6a and 6b whose positions and size are determined in accordance with the two-dimensional Fourier transform of the mask pattern 12.

Also, a spatial filter 15 having similarly a pair of transparent windows 15a and 15b is arranged at th Fourier transform plane 14 of a projection optical system 13 for projecting an image of the pattern 12 onto a wafer 17. Since a one-dimensional diffraction grating pattern is used as the pattern 12 in the present embodiment, the spatial filters 6 and 15 are each formed with the pair of transparent windows 6a and 6b or 15a and 15b so that each pair of transparent windows are placed in practically symmetrical positions on both sides of th optical axis of the optical system and their direction of arrangem nt coincid s optically with the line pitch direction of the grating pattern 12 within the plane of arrangem nt thereof. Also, the spatical filters 6 and 15 are r spectiv ly provided with driving mechanisms 7 and 16 each composed of a motor, a cam, etc., so that the spatial filters 6 and 15 are replaceabl with different ones depending on th mask pattern and the positions of the transparent windows 6a and 6b or 15a and 15b can undergo fin adjustment within the plan of arrangement of ach spatial filter. It is to be noted that the opening shape of

the transparent windows 6a, 6b and 15a, 15b of the spatial filters 6 and 15 can be determined arbitrarily and in Fig. 1 they are shown as having circular openings by way of example without any intention of limiting thereto. Further, while the spatial filters 6 and 15 are each composed of a light shielding plate formed with a pair of openings as transparent windows, the spatial filters 6 and 15 may each be composed of an electrooptic element such as a liquid crystal device or electro chromic device and in this case each of the illustrated driving mechanisms 7 and 16 is composed of electric circuitry for causing a transparent portion of a suitable size and shape at each of arbitrary limited areas of the electrooptical element.

With the exposure apparatus constructed as described above, the illuminating light produced from the mercury vapor lamp 1 arranged at the first focal point of the ellipsoidal mirror 2 is reflected by the ellipsoidal mirror 2 and the cold mirror 3 so that after the illuminating light has been condensed at the second focal point of the ellipsoidal mirror 2, it is passed through the condensing optical element 4 composed for example of a collimator lens or light beam distribution compensating cone prism and through the integrator element 5 comprising a group of fly-eye lenses thereby forming a substantial plane source of light in the plane of arrangement of the spacial filter 6. It is to be noted that in the present embodiment the so-called Köhler's illumination is used in which the secondary light source image of the integrator element 5 is formed at the Fourier transform plane 14 of the projection optical system 13. While this plane light source itself should project the illuminating light at various angles of incidence onto the mask from above as in the past, since the spatial filter 6 is arranged on this side of the condenser lens 10 in this case, only the collimated light beams passing through the transparent windows 6a and 6b of the spatial filter 6 fall on the mask 11 at given oblique angles of incidence and symmetrically with the optical axis within the plane crossing the lines of the grating pattern 12 through the relay lens 8, the mirror 9 and the condenser lens 10.

When the collimated beams are projected onto the pattern 12 of the mask 11, diffracted beams of the 0-order, ± first-orders, ± second-orders and higher-orders are produced from the pattern 12. Here, since the transparent windows 6a and 6b of the spatial filter 6 arranged at the Fourier transform plane 14 of the illuminating optical system determine the distances of the collimated light beams from the optical axis as well as their positions about the optical axis and the condenser lens 10 determines the angles of incidence of the collimated light beams onto the pattern 12 of the mask 11, of the diffracted beams of the various orders those directed to the projection optical system 13 from each window are practically only either one of the ± first-order diffracted beams and the 0-order diffracted beam and the other diffracted beams are very small in quantity. As a result, principal diffracted beam spots due to either of the ± first-order diffracted beams and the 0-order diffracted beam and diffracted beam spots of the other undesired orders are formed at the Fourier transform plane of the projection optical system 13 in accordance with the Fourier expanded pattern. The other spatial filter 14 arranged at the Fourier transform plane of the projection optical system 13 selectively passes only the principal diffracted beams toward the wafer 17 and intercepts the diffracted beams of the other undesired orders. In this case, the positions of the spatial filters 6 and 15 are adjusted relative to the pattern 12 of the mask 11 by the driving mechanisms 7 and 16, respectively, so that the principal diffracted beams or either of the ± first-order diffracted beams and the 0-order diffracted beams are passed with the maximum intensity and the other undesired diffracted beams are blocked completely.

Fig. 2 shows schematically the basic optical path construction for the illuminating light in the exposure apparatus according to the present embodiment. While, in the Figure, the spatial filter 6 is arranged just above the condenser lens 10 for purposes of illustration, this position is a conjugate plane to the spatial filter 6 of Fig. 1 with respect to the relay lens 8 and this construction is substantially the same in function and effect with the case of Fig. 1.

In Fig. 2, if NA represents the numerical aperture of the projection optical system and λ the wavelength of the illuminating light, the pitch of the pattern 12 is selected to be 0.75 times λ /NA and the line-to-space ratio of the pattern 12 is selected 1:1 (the duty ratio of the grating is 0.5). In this case, with the wavelength λ taken into consideration, the Fourier transform q(u, v) of the pattern 12 is given as follows if the pattern 12 is represented by p(x, y)

$$q(u,v) = \iint p(x,y) \cdot \exp\{-2\pi i(ux+vy)/\lambda\}dxdy$$

Also, where the pattern 12 is uniform vertically or in the y-direction and varies regularly in the x-direction as shown in Fig. 4, if th x-direction line-to-space ratio is 1:1 and the line pitch is 0.75λ /NA, the following equation h lds

$$q(u,v) = q_1(u) \times q_2(v)$$

therefore, the following hold

$$
\begin{array}{ll}
q_1(u) = 1, & u = 0 \\
q_1(u) = 0.637, & u = \pm NA/0.75 \\
q_1(u) = -0.212, & u = \pm 3\ NA/0.75 \\
\vdots & \vdots \\
q_1(u) = 0.637/(2n-1)(-1)^{(n+1)}, & u = \pm (2n-1) \cdot NA/0.75 \\
q_1(u) = 0, & u \text{ is other than the foregoing}
\end{array}
$$

and

$$
\begin{array}{ll}
q_2(v) = 1, & v = 0 \\
q_2(v) = 0, & v \neq 0
\end{array}
$$

Figs. 3 and 5a are respectively plan views of the spatial filter 6 for the illumination optical system and the spatial filter 15 for the projection optical system which are used in the present embodiment.

The spatial filters 6 and 15 are such that with the following showing the peak values of the Fourier transform energy distribution $|q(u,v)|^2$

$(u,v) = (0, 0), (\pm NA/0.75, 0), (\pm 3\ NA/0.75, 0) \cdots$

and with the following showing 1/2 thereof

$(u,v) = (0, 0), (\pm NA/1.5, 0), (\pm 2\ NA, 0) \cdots$

the positions falling within the numerical aperture of the projection optical system 13 or the following

$(u,v) = (\pm NA/1.5, 0)$

or their nearby positions are selected to be the transparent windows 6a, 6b and 15a, 15b, respectively, and the positions or the following are selected to be the light shielding portions.

$(u,v) = (0, 0)$

It is to be noted that the positions of the spatial filters 6 and 15 or the following are respectively adjusted by the driving mechanisms 7 and 16 of Fig. 1 so as to coincide with the optical axes of the illumination optical system (1 to 10) and the projection optical system 13, respectively. Each of the spatial filters 6 and 15 may for example be composed of an opaque metal sheet which is selectively removed to form its transparent windows or a transparent holding sheet coated with a thin film of metal or the like by patterning to form its transparent windows. Also, while, in the embodiment shown in Fig. 1, the illuminating light source comprises the mercury vapor lamp 1, it may be composed of any other light source such as a laser light source. Further, while, in this embodiment, the pattern 12 of the mask 11 comprises a line-and-space pattern varying only in the x-direction at a duty ratio of 1:1, the present invention is also applicable to other patterns varying in a plurality of arbitrary directions regularly.

In Fig. 2, as the r sult of the arrang ment of the illustrated spatial filter 6 at the Fourier transform plane of the pattern 12 within the illuminating optical system for the pattern 12 having th line pitch of $0.75\lambda/NA$, the illuminating light Li for illuminating th patt rn 12 is limited for xample to colliminated light beams Liℓ and Lir. When the illuminating beams Liℓ and Lir are projected onto the pattern 12, their diffracted beams are produced from th pattern 12.

Assuming that th 0-order diffracted beam and the +first-ord r diffracted beam of the illuminating beam

Lil are respectively represented as Ll0 and Ll1 and the 0-order diffracted beam and the -first-order diffracted beam of the illuminating beam Lir as Lr0 and Lr1, the deviation angles between the diffracted beams Ll0 and Ll1 and between diffracted beams Lr0 and Lr1 are both given by the following

$$\sin\theta = \lambda / (\text{line pitch of pattern } 12)$$
$$= \lambda / (0.75\lambda / NA)$$
$$= NA/ 0.75$$

and since the incident beams Lil and Lir are initially apart by 2NA/1.5 from each other, at the Fourier transform plane of the projection optical system 13 the diffracted beams Ll0 and Lr1 pass through the same first optical path, whereas the diffracted beams Lr0 and Ll1 pass through the same second optical path. In this case, the first and second optical paths are symmetrically apart by the equal distance from the optical axis of the projection optical system 13.

Fig. 6a shows schematically the intensity distribution of the diffracted beams at the Fourier transform plane 14 of the projection optical system 13. In Fig. 6a, a spot 22l formed at the Fourier transform plane 14 is the result of the convergence of the diffracted beams Lr0 and Ll1 and similarly a spot 22r is one resulting from the convergence of the diffracted beams Ll0 and Lr1.

As will be seen from Fig. 6a, in accordance with the present embodiment each combination of the 0-order diffracted beam and the +first-order or -first-order diffracted beam from the pattern 12 having a line pitch of 0.75 λ /NA finer than λ /NA can be condensed almost 100% on the wafer 17 through the projection optical system 13, so that even in the case of finer pattern than that pitch (λ /NA) representing the limit to the resolution of the conventional exposure apparatus, the use of the spatial filters having the transparent windows of the dimensions corresponding to the line pitches of the mask patterns makes it possible to effect the exposure and transfer with sufficient resolutions.

Referring now to Fig. 5b, there is illustrated a spatial filter which is used in the case of a mask pattern consisting of a line-and-space pattern crossing in the x and y directions. Also, Fig. 6b shows the conditions of the spots formed in correspondence to the diffracted beams at the Fourier transform plane of the projection optical system in the case of Fig. 5b.

Next, the resolution of the pattern on the substrate 17 in the exposure apparatus of the present embodiment will be described in comparison with exposure apparatus according to various reference examples.

= In the case of reference examples =

Figs. 7 and 8 respectively show schematically the optical path construction of the illuminating light (Fig. 7) and the light quantity distribution at the Fourier transform plane of the projection optical system (Fig. 8) in the projection exposure apparatus shown in the previously mentioned Japanese Laid-Open Patent Application No.2-50417 cited as a reference example. It is to be noted that in the Figures the components which are the same in operation and function as in the apparatus according to the above-mentioned embodiment of the present invention are designated by the same reference numerals as in Fig. 2.

In Fig. 7, an aperture stop 6A (a spatial filter having a circular transparent window formed concentrically with the optical axis) is arranged at the Fourier transform plane of the illumination optical system thereby limiting the angle of incidence of the illuminating light on the mask 11. The 0-order diffracted beam (the solid lines) and the ± first-order diffracted beams (the broken lines) produced from the pattern 12 of the mask 11 are both entered into the projection optical system 13 and proceed along separate optical paths so that a spot 20l of the +first-order diffracted beam, a spot 20c of the 0-order diffracted beam and a spot 20r of the -first-order diffracted beam are formed at separate positions apart from one another in the Fourier transform plane 14 as shown in Fig. 8.

Also, Figs. 9 and 10 respectively show schematically the optical path construction of the illuminating light (Fig. 9) and the light quantity distribution at the Fourier transform plane of the projection optical system (Fig. 10) in a projection exposure apparatus cited as another reference example. In this another reference example, the apertur stop 6A of Fig. 7 is replaced with a spatial filter 6B formed with an annular transparent window which is concentric with the optical axis.

In Fig. 9, provided at th Fourier transform plane of the illuminati n optical system is the spatial filter 6B having the annular transparent window formed conc ntrically with th optical axis so that th illuminating

light is obliquely projected or in an inverse conical form onto the mask 11. As a result, at least within the plane trav rsing the optical axis in the line pitch direction of the pattern 12, as in the case of th embodiment of the present invention shown in Fig. 2, the 0-order diffracted beam (the solid lines) is obliquely entered like the first-order diffracted beams (the broken lines) into the projection optical system so that they pass through the projection optical system while partly overlapping the separate first-order diffracted beams entering from the opposite sides and the reach up to the wafer 17, thereby forming a projected image. At this time, a doughnut shaped spot 21c of the 0-order diffracted beam which is concentric with the optical axis as well as a spot 21ℓ of the +first-order diffracted beam and a spot 21r of the -first-order diffracted beam which are adjacent to and partly overlapping the spot 21c are formed in the Fourier transform plane 14 of the projection optical system 13 as shown in Fig. 10. In this case, the large parts of the spots 21ℓ and 21r extend to the outside of the projection optical system 13 and the beams of these externally extended portions are eclipsed by the lens barrel of the projection optical system.

= In the case of the embodiment of the present invention =

~~Figs. 11 to 14 are diagrams showing the distributions of the light intensities I of the projected images on~~ the wafer 17 in the embodiment of the present invention shown in Fig. 2 in comparison with the cases of Figs. 7 and 9. These light intensities are in conformity with the results obtained by calculation with respect to within the plane traversing the optical axis in the line pitch direction of the pattern 12 on the substrate with the NA of the projection optical system being selected 0.5, the wavelength λ of the illuminating light selected 0.365μ m and the pattern line pitch of the mask pattern 12 selected 0.5μ m (about 0.685x λ /NA) in terms of the value on the wafer 17 obtained from the magnification of the projection optical system 13.

Fig. 11 shows the light intensity distribution of the projected image formed on the substrate by the exposure apparatus according to the previously mentioned embodiment (Fig. 2) of the present invention and it will be seen that this intensity distribution has a sufficient light-and-dark contrast of the edges of the pattern.

Fig. 12 shows the light intensity distribution of the projected image on the substrate in the case where the diameter of the aperture stop 6A is relatively small and the ratio of the numerical aperture of the illumination optical system to the numerical aperture of the projection optical system or the so-called σ value is selected 0.5 in the reference example of Fig. 7. In this case, it will be seen that since the ratio (σ value) of the numerical aperture of the illumination optical system to the numerical aperture of the projection optical system is selected 0.5, the projected image has a flat light intensity distribution without practically any light-and-dark contrast.

Fig. 13 shows the light intensity distribution of the projected image in the case where the opening of the aperture stop 6A is relatively large and the ratio of the numerical aperture of the illumination optical system to the numerical aperture of the projection optical system or the so-called σ value is selected 0.9 in the reference example of Fig. 7. In this case, it will be seen that while the light-and-dark contrast of the projected image is greater than in the case of Fig. 12 due to the fact that the ratio (σ value) of the numerical aperture of the illumination optical system to the numerical aperture of the projection optical system is selected 0.9, the light intensity distribution is still relatively large in 0-order diffracted beam component and comparatively flat and thus it is unsatisfactory from the standpoint of the light-response characteristic of the resist.

Fig. 14 shows the light intensity distribution of the projected image on the substrate in the case of the reference example of Fig. 9 and in this case the inner and outer edges of the annular transparent window of the spatial filter 6B respectively correspond to 0.7 and 0.9 in terms of the σ value. While this projected image is stronger in light-and-dark contrast than in the case of Fig. 12, the light intensity distribution is still relatively large in 0-order diffracted beam component and comparatively flat and thus it is still insufficient from the standpoint of the light-response characteristic of the resist.

As will be seen from Figs. 11 to 14, in accordance with the embodiment of the present invention shown in Fig. 2 the substantial resolution of the projected image on the substrate is greatly improved as compared with the cases of Figs. 7 and 9.

Then, in the case of Fig. 9, if a spatial filter of the same type as the spatial filter 15 used in the previously mentioned embodiment is similarly arranged at the Fourier transform plan of the projection optical system 13, the diffracted beams of the 0-ord r and ± first-orders can be selectively cond nsed at the portions indicated by the cross hatching in Fig. 10 so as to slightly improve the resolution of the projected image on the wafer 17 as compared with the case of Fig. 14. In this cas , however, ther is the unavoidable disadvantage that the utilization rat of the illuminating light incident on the projection optical system is decreased greatly and the energy component not contributing to the exposure is accumulated

within the projection optical system thereby changing its optical characteristics. In the embodiment of Fig. 2 according to the present invention, practically all the energy of the illuminating light incid nt on the projection optical system contributes to the exposure.

Then, even in the past, there has been known the technique of positively utilizing the diffracted beams from a mask pattern to improve the resolution of the projection optical system and this technique is such that dielectric members for reversing the phase of the illuminating light, i.e., the so-called phase shifters are arranged alternately with the transparent portions of the pattern. However, actually it is extremely difficult ot properly provide such phase shifters on a complicate semiconductor circuit pattern and no inspection method for phase shifted photomasks has been established as yet.

With the embodiment of Fig. 2 according to the present invention, while its effect of improving the resolution of the projected image is comparable to that of the phase shifters, it is possible to use a conventional photomask without phase shifters as such and it is possible to follow the conventional photomask inspection techniques as such.

Also, while the use of the phase shifters has the effect of increasing in effect the focus depth of the projection optical system, even in the embodiment of Fig. 2, as shown in Fig. 6a, the spots 22ℓ and 22r at the Fourier transform plane 14 are in the equidistant positions from the center of the pupil so that they are less susceptible to the effect of the front wave aberrations due to the defocusing as mentioned previously and a large focus depth is obtained.

While, in the above-described embodiment, the mask pattern comprises by way of example a line-and-space pattern which varies regularly in the x-direction, the foregoing effect can be fully attained on the ordinary patterns other than the line-and-space pattern by combining proper spatial filters in the respective cases. Then, while the number of the windows in the spatial filer is two when the mask pattern has a one-dimensional variation which varies only in the x-direction, in the case of a pattern having a plurality of n dimensional variations, the number of the required transpared windows is 2n in accordance with the spatial frequency of the pattern. For instance, in the case of a diffraction grating pattern having a two-dimensional variation in the x and y directions, for example, as shown in Fig. 5b, it is necessary to form two pairs or total of four transparent windows arranged on the cross in the spatial filter so that the four corresponding diffracted beam spots are formed at the Fourier transform plane of the projection optical system as shown in Fig. 6b.

Also, while, in the above-described embodiment, the light shielding portion of each spatial filter is considered as one which does not transmit the illuminating light at all for purposes of simplifying the description, this portion may be constructed as a light attenuating portion having a certain predetermined degree of light transmittance so that in this case, only the contrast of a projected image of any specified fine pattern can be selectively improved during the exposure by the front beam cross-section of the illuminating light as in the past.

Further, while the description of the embodiment has been made with particular emphasis on the spatial filter within the illumination optical system, it can be considered that the spatial filter within the projection optical system is basically the same in function and effect. In other words, the same effect can be obtained by arranging a spatial filter satisfying the above-mentioned conditions at least at one of substantially the Fourier transform plane of the illumination optical system and substantially the Fourier transform plane of the projection optical system. Also, as for example, it is possible to arrange a spatial filter such as shown in Fig. 3 at the Fourier transform plane of the illumination optical system and a spatial filter having an annular transparent window at the Fourier transform plane of the projection optical system. In this case, it is needless to say that with the latter spatial filter having the annular transparent window, the annular transparent window must be arranged in such a manner that both of the 0-order diffracted beam and the +first-order (or the -first-order) diffracted beam from the mask pattern are passed together through it. Further, by using the two spatial filters in combination, there is the effect of cutting off the diffused reflection from the projection optical system or the wafer and preventing the stray light rays.

Still further, while, in the above-described embodiment, the description is mainly directed to the case where the spatial filters (6, 15) are mechanically changed in dependence on the mask pattern, if, for example, a spatial filter comprising a liquid crystal device, an EC (electro chromic) device or the like is used, there are advantages that not only the use of any mechanical filter changing mechanism is eliminated but also the adjustment and change of the positions of transparent windows is attained by means of electric circuitry, that the apparatus is made m re compact in size and that the adjustm nt and chang of the size, shap and position of transparent windows can be effected easily and at high speeds.

The embodiments described h r in are for the purpose of illustration without any intention of limitation and the technical scope of the present invention is intended to b limited in accordance with the statem nt of the appended claims.

Claims

1. In an exposure method for transferring a fine pattern on a mask onto a substrate by use of a projection exposure apparatus including an illumination optical system for irradiating an illuminating light on the mask and a projection optical system for projecting an image of the fine pattern on the illuminated mask onto the substrate, the improvement wherein:
   said illuminating light is obliquely irradiated on said mask in such a manner that either one of ± first-order diffracted beams and a 0-order diffracted beam produced from the fine pattern on said illuminated mask are respectively passed apart by an equal distance from an optical axis of said projection optical system at or in the vicinity of the Fourier transform plane within said projection optical system with respect to the fine pattern on said mask.

2. An exposure method according to claim 1, wherein the other beams than either of said ± first-order diffracted beams and said 0-order diffracted beam are prevented from reaching said substrate.

3. An exposure apparatus comprising:
   an illumination optical system for irradiating an illuminating light on a mask,
   a projection optical system for projecting an image of a fine pattern on said illuminated mask onto a substrate, and
   spatial filter means arranged at least at one of the Fourier transform plane within said illumination optical system and the Fourier transform plane within said projection optical system with respect to the fine pattern on said mask or a position near thereto, said spatial filter means including at least a pair of window means respectively defined by separate limited areas to have a comparatively high light transmittance than the surrounding thereof and arranged at positions apart from an optical axis of said illumination optical system or said projection optical system within which said spatial filter is arranged.

4. An exposure apparatus according to claim 3, wherein said spatial filter means includes two window means forming a symmetrical pair with the optical axis of said illumination optical system or said projection optical system in which said spatial filter is arranged.

5. An exposure apparatus according to claim 3, wherein said spatial filter means includes 2n window means (where n is a natural number).

6. An exposure apparatus according to claim 3, wherein said spatial filter means includes said window means at each of a plurarilty of positions determined in accordance with a Fourier transform pattern of said fine pattern.

7. An exposure apparatus according to claim 3, wherein said illumination optical system comprises an optical integrator including fly-eye lenses or the like, and wherein said spatial filter means is arranged at a position near to an exit end of said optical integrator.

8. An exposure apparatus according to claim 3, wherein the other portion of said spatial filter means than said window means is formed into a light shielding portion.

9. An exposure apparatus according to claim 3, wherein the other portion of said spatial filter means than said window means is formed into a light attenuating portion.

10. An exposure apparatus according to claim 3, wherein said spatial filter means is arranged within said illumination optical system, and wherein the position of each of said window means is selected such that either one of ± first-order diffracted beams and a 0-order diffracted beam produced from said fine pattern are separately passed apart by substantially an equal distance from the optical axis of said projection optical system at the Fourier transform plane within said projection optical system with respect to the fine pattern on said mask.

11. An exposure apparatus according to claim 4, wh rein said spatial filter means is arranged within said illumination optical system, and wherein said pair compris s first window means and second window means optical-axially symmetric with said first window means, said first and second window means being positioned such that ith r on of ± first-order diffracted beams and a 0-order diffracted beam

produced from said fine pattern by the irradiation of a beam of said illuminating light reaching said mask through said first window means and either one of ± first-order diffracted beams and a 0-order diffracted beam produced from said fine pattern by the irradiation of another beam of said illuminating light reaching said mask through said second window means are alternatively passed through separate first and second optical paths which are respectively apart by substantially the same distance from the optical axis of said projection optical system at the Fourier transform plane of said projection optical system, that is, either one of the ± first-order diffracted beams produced by said illuminating light through said first window means and the 0-order diffracted beam produced by said illuminating light through said second window means are passed through said first optical path, and either one of the ± first-order diffracted beams produced by said illuminating light through said second window means and the 0-order diffracted beam produced by said illuminating light through said first window means are passed through said second optical path.

12. An exposure apparatus according to claim 3, further comprising drive means to vary for adjusting or changing purposes at least one of the angular positions about said optical axis and the distances apart from said optical axis of said window means in accordance with the fine pattern on said mask.

13. An exposure apparatus according to claim 12, wherein said spatial filter means comprises a light shielding or light attenuating plate element having at least a pair of window means, and wherein said drive means includes a mechanism for replacing said plate element with another plate element having window means at relatively different positions.

14. An exposure apparatus according to claim 12, wherein said spatial means comprises an electrooptical element whereby limited areas in at least a pair of arbitrary positions are respectively made transparent and opaque, and wherein said drive means includes electric circuit means for driving said electrooptical element to make said limited areas transparent and opaque, respectively.

15. An exposure apparatus for projecting a fine pattern on a mask onto a substrate, said apparatus comprising:

an illumination optical system for irradiating an illuminating light on a mask,

a projection optical system for projecting an image of a fine pattern on said illuminated mask onto a substrate, and

optical limiting means for limiting the light intensity distribution of said illuminating light at the Fourier transform plane within said illumination optical system with respect to the fine pattern on said mask or a position near thereto such that said light intensity becomes maximum in each of at least two locations apart from the optical axis of said illumination optical system,

whereby the centers of said locations are separated from each other by a spacing selected in accordance with the fineness of the fine pattern on said mask.

16. An exposure apparatus according to claim 15, wherein said illumination optical system includes an optical element whereby the illuminating light beams from said two locations provided by said optical limiting means are substantially symmetrically inclined on said mask.

17. An exposure apparatus for projecting a fine pattern on a mask onto a substrate, said apparatus comprising:

an illumination optical system for producing an illuminating light for illuminating a mask,

an optical element for inclining said illuminating light on said mask, and

a projection optical system having an optical axis substantially perpendicular to said mask for projecting an image of the fine pattern on said mask onto a substrate by light beams produced from said mask by said inclined illuminating light,

whereby either one of ± first-order diffracted beams and a 0-order diffracted beam produced from the fine pattern on said mask by each said light beam are respectively projected onto said projection optical system at substantially symmetrical angl s of inclination with respect to a lin substantially perpendicular to said mask.

18. An exposure apparatus according to claim 17, wherein said illumination optical syst m includes an optical element whereby the illuminating light beams provided from said two locations by said optical limiting means are substantially symm trically inclined on said mask.

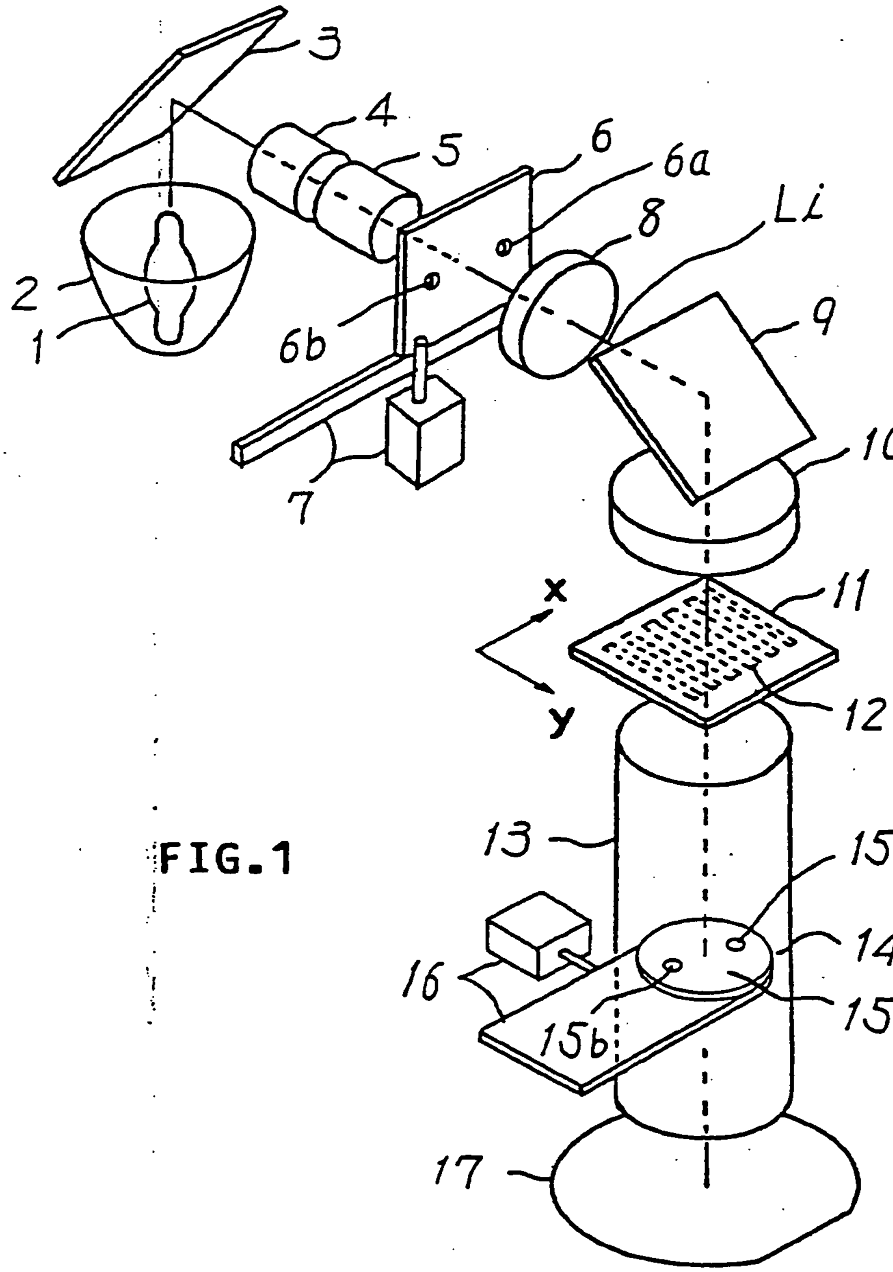

FIG.1

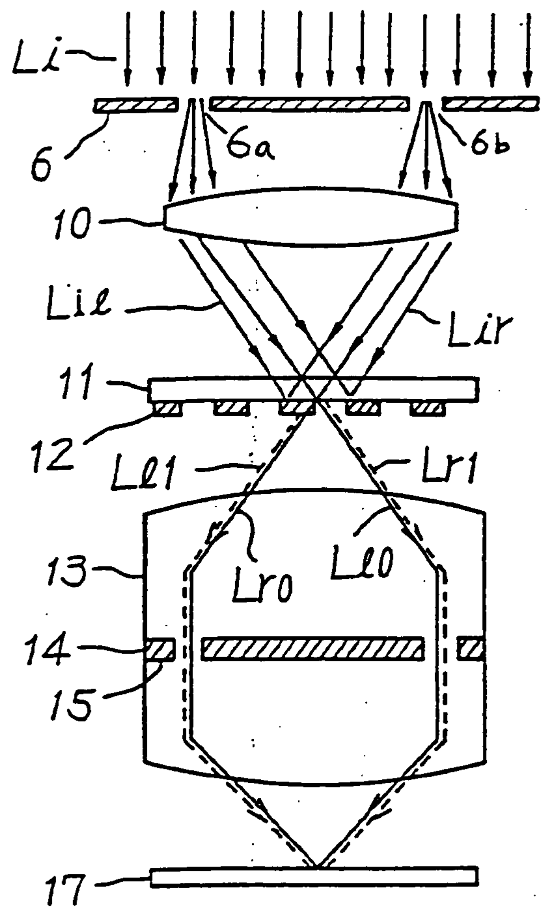

FIG.2

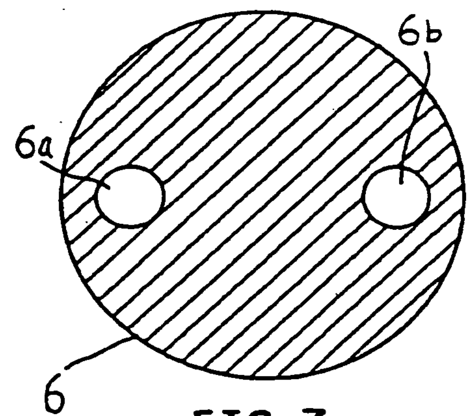

FIG.3

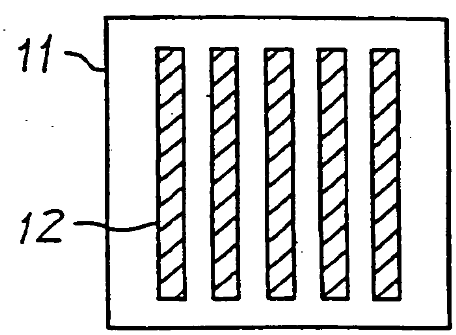

FIG.4

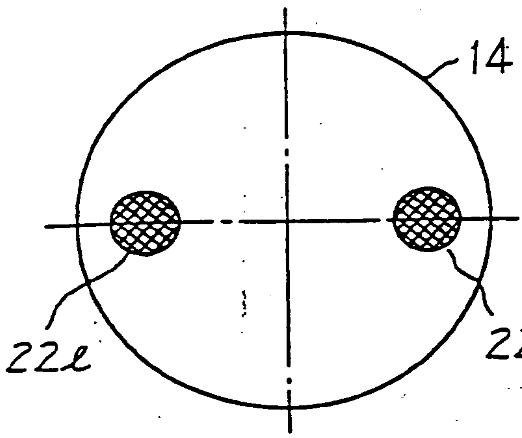

FIG.6a

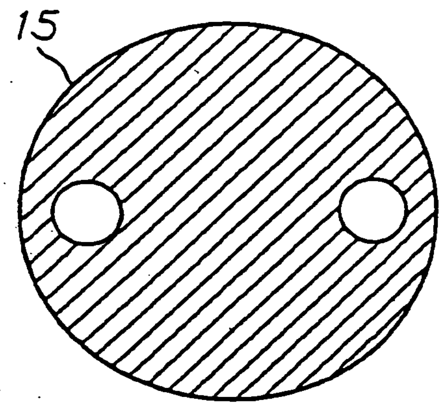

FIG.5a

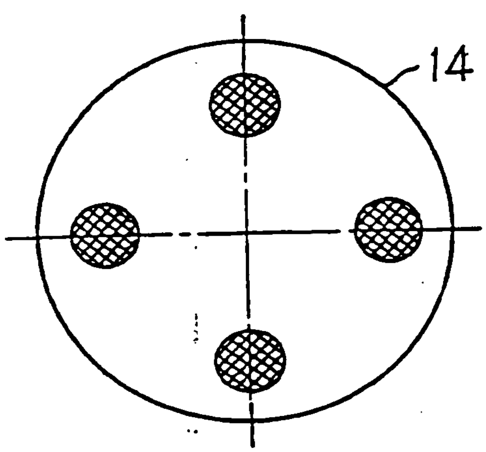

FIG.6b

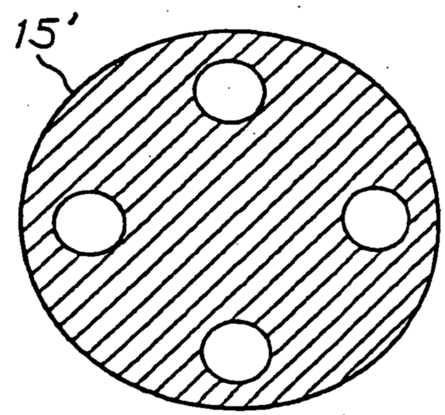

FIG.5b

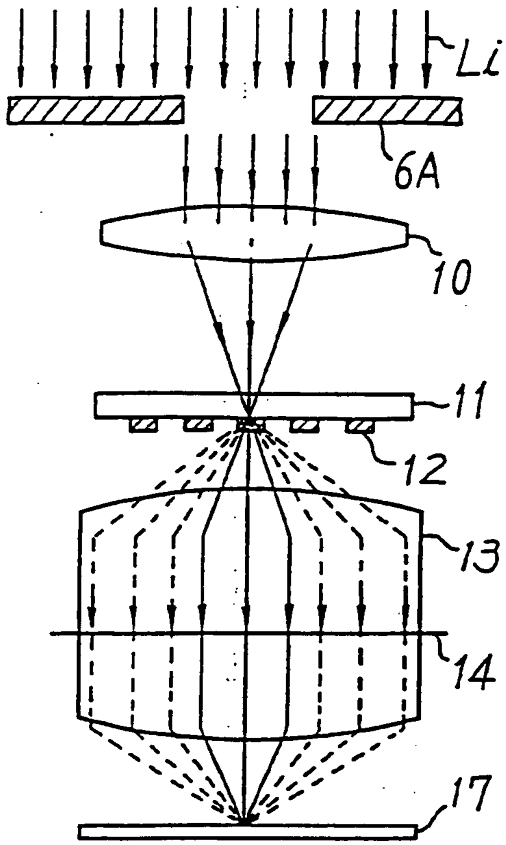

FIG.7

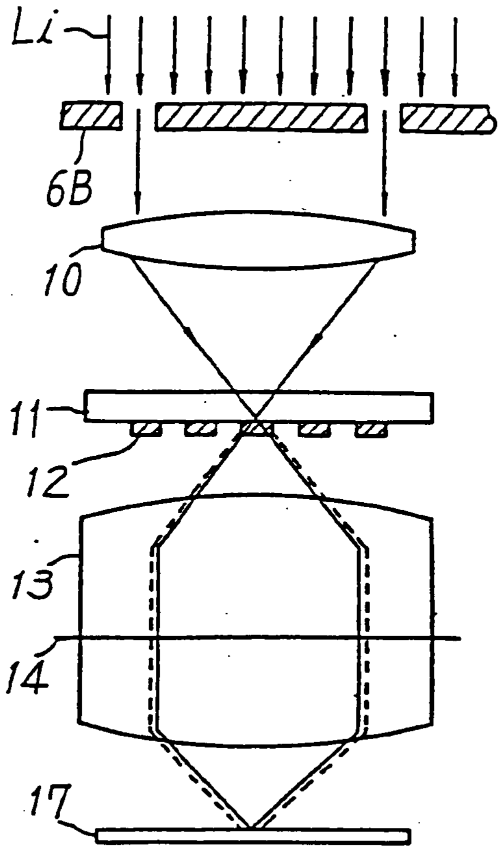

FIG.9

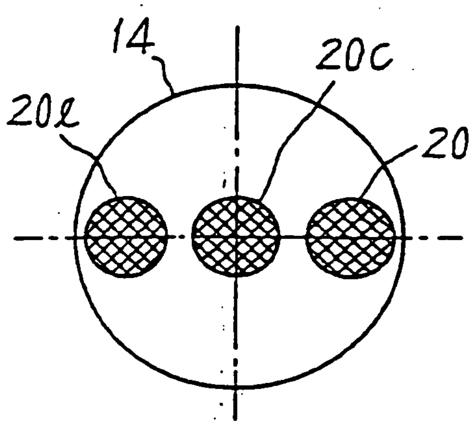

FIG.8

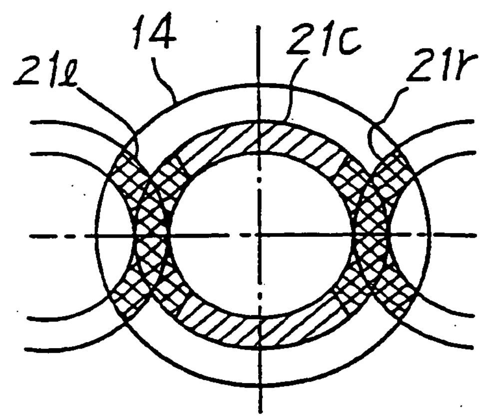

FIG.10

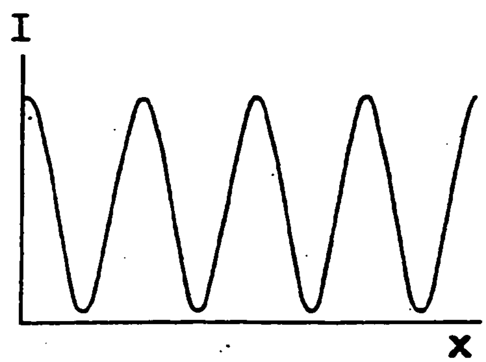

FIG.11

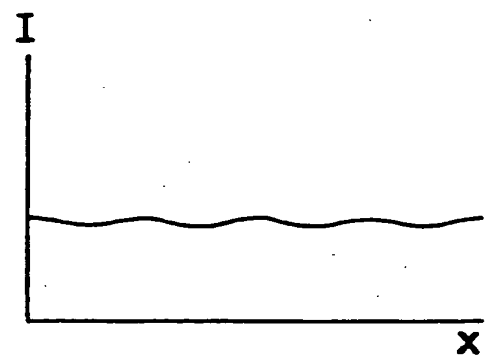

FIG.12

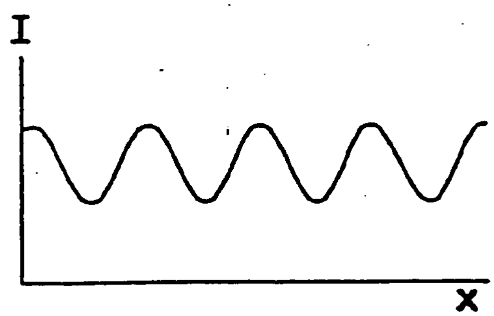

FIG.13

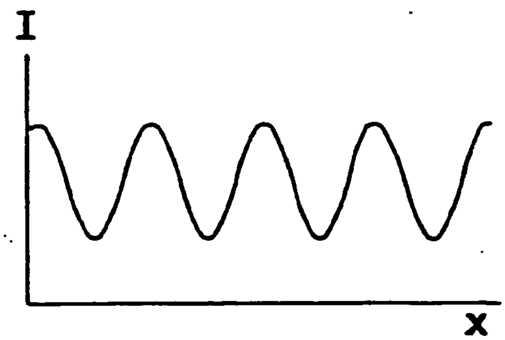

FIG.14

INTERNATIONAL SEARCH REPORT

International Application No PCT/JP91/01103

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) [6]

According to International Patent Classification (IPC) or to both National Classification and IPC

Int. Cl^{5} H01L21/027

II. FIELDS SEARCHED

Minimum Documentation Searched [7]

Classification System	Classification Symbols
IPC	H01L21/027, G03F7/20

Documentation Searched other than Minimum Documentation to the Extent that such Documents are included in the Fields Searched [8]

Jitsuyo Shinan Koho	1970 - 1991
Kokai Jitsuyo Shinan Koho	1971 - 1991

III. DOCUMENTS CONSIDERED TO BE RELEVANT [9]

Category *	Citation of Document, [11] with indication, where appropriate, of the relevant passages [12]	Relevant to Claim No. [13]
A	JP, A, 59-83165 (Hitachi, Ltd.), May 14, 1984 (14. 05. 84), (Family: none)	1-18

* Special categories of cited documents: [10]
- "A" document defining the general state of the art which is not considered to be of particular relevance
- "E" earlier document but published on or after the international filing date
- "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
- "O" document referring to an oral disclosure, use, exhibition or other means
- "P" document published prior to the international filing date but later than the priority date claimed
- "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
- "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step
- "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
- "&" document member of the same patent family

IV. CERTIFICATION

Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report
October 18, 1991 (18. 10. 91)	November 5, 1991 (05. 11. 91)
International Searching Authority	**Signature of Authorized Officer**
Japanese Patent Office	